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OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1953 THANKSGIVING MEETING

AT

CHICAGO, ILL.

November 27 and 28, 1953

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OF THE

AMERICAN PHYSICAL SOCIETY

1953 THANKSGIVING MEETING AT CHICAGO, ILLINOIS, NOVEMBER 27–28, 1953

THE **University of Chicago** will resume, after a two-year gap, its traditional role of host to the American Physical Society at the Thanksgiving meeting. The dates will be **Friday and Saturday, November 27 and 28, 1953.** In the new buildings of the Research Institutes—on Ellis Avenue between 56th and 57th Streets—the conference rooms will be put at the disposal of our members for registration and for informal gatherings. The scientific sessions will be held in halls in other buildings familiar in past years to our members. The programme, as is usual at the Thanksgiving meetings, will be widely diversified; mesons, other cosmic-ray particles, and semi-conductors are especially well represented. Particular gratitude is due Mrs. Dorothy C. Johnson for attending to the multifarious details of the meeting.

The **official hotel** is the Windermere, at 1642 East 56th Street—east of the Illinois Central, and about three-quarters of a mile east of the University. Should it receive more bookings than it can accommodate, the overflow will be allotted to other hotels of the region. Write to the hotel direct, not forgetting to say that you are coming to our meeting.

The **registration desk** will be located in Room 480 of the Research Institute, at 5630 Ellis Avenue. All members and guests are asked to register, and to pay a registration fee of one dollar. Consult the nearby bulletin board for notice of messages, and for the names of the post-deadline papers if any.

Invited papers will be given by O. H. Arroe, H. H. Barschall, G. Bernardini, S. Bernstein, E. Fermi, M. Gell-Mann, R. Gomer, P. S. Jastram, E. J. Konopinski, N. H. Nachtrieb, T. B. Novey, C. L. Oxley, L. D. Roberts, C. P. Slichter, R. M. Steffen, and R. W. Thompson. Marcel Schein and J. A. Simpson will report on the cosmic-ray conference of July, 1954, at Bagnères-de-Bigorre.

One hundred and forty-two contributed papers are distributed among fourteen sessions.

The **banquet of the Society** will be held on Friday evening in Hutchinson Commons (southwest corner of University Avenue and 57th Street). The price is three dollars. Advance reservations will be welcomed; use the form on the inside back-cover page. A deadline-hour will be set for purchase of tickets at the registration desk and stated on the bulletin board. After this deadline, tickets reserved but not called for nor paid for will be sold to the first comers. We lost money at a recent meeting through ordering more dinners than tickets had been bought for; we shall be more cautious this time. The after-dinner speakers will be S. K. Allison, D. H. Loughridge, and R. S. Mulliken.

Post-deadline ten-minute papers, pertaining to very recent achievements of very special importance, will be considered for admission to a special supplementary programme if the abstracts are received between Monday, November 9, and Friday, November 21 (both dates inclusive), at the office of the American Physical Society. The titles of such papers as may be accepted will be announced on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule at the end of Session H.

The **Council** will meet at 4:15 P.M. on Friday in Room 180 of the Research Institutes building, at 5630 Ellis Avenue, unless contrary notice is distributed to its members.

For the **next three meetings** of the Society (apart from the Stanford meeting, for which deadline is past), see page 5. For dates and deadlines of **future meetings,** and for the rules imposed on abstracts, see page 5.

Titles and abstracts of papers contributed to the 1953 Thanksgiving meeting are printed hereinafter.

and in exactly this form they will reappear in a future issue of *The Physical Review*. Errata will be printed on an adjacent page of *The Physical Review* if received not later than Friday, December 11, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. Do not send in the abstract marked with corrections: write out the corrections in the form "instead of . . . read . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Second Announcement of the 1954 Annual Meeting

The 1954 Annual Meeting will be held in New York City on January 28–30, 1954. Deadline will be November 20, 1953. Preliminary announcement of this meeting was made in the September *Bulletin*; consult it for details.

Preliminary Announcement of the 1954 February meeting at Austin, Texas

The expansion of physics in the Southwestern United States and in Mexico has led the physicists of that area to solicit that a meeting of the American Physical Society be held annually in their region. The Council of the Society has authorized a meeting to be held on **Friday and Saturday, February 26 and 27, 1954,** in the buildings of the University of Texas at Austin, Texas. The official hotel will be the Driskill: reservations should be made as early as possible by letter to the hotel with mention that the writer is coming for the meeting of the American Physical Society. Rates are $4 for single rooms, $7 and $8 for twin-bed rooms, and $6.50 for double room with double bed.

Deadline for this meeting will be **Wednesday, December 30, 1953.** Abstracts of contributed papers are to be sent to the address below.

Summons cards will not be issued henceforward except in emergencies. On a separate page of the *Bulletin* (page 5 on this occasion) meeting dates and deadline dates will be listed for the future so far as established, and on the same page the rules for preparation of abstracts will be stated.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Preliminary Announcement of the 1954 March meeting at Detroit and Ann Arbor, Michigan

The 1954 March meeting of the American Physical Society will be held on Thursday, Friday, and Saturday, March 18, 19, and 20. Like its predecessor of 1953, it will be held in two cities: in Detroit on Thursday and Saturday, in Ann Arbor at the University of Michigan on Friday. (Special arrangements will be made for conveying our members between the cities on Friday, probably by train). Also, as in 1953, it will include the meetings of the Divisions of High-Polymer Physics and Solid-State Physics, but will not be limited to topics in their fields. The official hotel will be the Sheraton-Cadillac in Detroit: reservations should be made as early as possible (and the hotel would like them a month in advance). Rates range from $5 upward for single rooms, $10 upwards for twin-bed rooms, and $9 upwards for double rooms with double beds.

Deadline for this meeting will be **Friday, January 15, 1954.** Abstracts of contributed papers are to be sent to the address below.

Summons cards will not be issued henceforward except in emergencies. On a separate page of the *Bulletin* (page 5 on this occasion), meeting dates and deadline dates will be listed for the future so far as established, and on the same page the rules for preparation of abstracts will be stated.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

(Please keep this page on file!)

MEETINGS AND DEADLINES FOR THE SEASON 1953–1954

I. Meetings east of the Rockies

Place	*Meeting dates*	*Deadline date*
Chicago	November 27–28, 1953	past
New York	January 28–30, 1954	November 20, 1953
Austin	February 26–27	December 30
Detroit-Ann Arbor	March 18–20	January 15, 1954
Washington	April 29–30, May 1	February 19
Minneapolis	June 28–30	April 30

Abstracts of contributed papers for the foregoing meetings are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York. To avoid danger of confusion, please do not send abstracts for any meeting until the deadline date of the previous meeting is past.

II. Meetings west of the Rockies

Stanford	December 28–30, 1953	past
Seattle	July 7–10, 1954	May 5, 1954

Abstracts of contributed papers for the Seattle meeting are to be sent to J. Kaplan, University of California, Los Angeles 24, California.

RULES IMPOSED ON ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to ten words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

The use of special delivery is perilous. For reasons which we do not pretend to understand, special-delivery stamps sometimes produce the inverse of the effect expected. Thus, eleven special-delivery letters, postmarked September 23 at the points of origin, and September 24 at New York, were delivered at the office of the Society on September 30. This is not the first time that the like has happened.

EPITOME OF THE 1953 CHICAGO MEETING

(Personal names are those of invited speakers, except at the ends of lines where they are names of halls.)

Friday Morning

A. Semiconductors. Mandel.
B. Cosmic rays; particles other than pi mesons. Kent.
C. Beta emitters; Steffen, Novey. Eckhart.
D. Barschall, Roberts, Bernstein. Oriental.

Friday Afternoon

F. Fermi; pi mesons. Mandel.
G. Magnetic resonance, electronic and nuclear; quadrupole resonance; Slichter. Kent.
H. Apparatus of nuclear physics; post-deadline papers, if any. Eckhart.
I. Whiskers and solid-state physics. Oriental.

Friday Evening

Banquet of the American Physical Society; Allison, Loughridge, Mulliken. Hutchinson Commons.

Saturday Morning

K. Reactions of transmutation; nuclear energy levels. Eckhart.
L. Nachtrieb, Gomer; general physics. Rosenwald.
M. Mostly elastic scattering; Jastram, Oxley. Kent.
N. Electron physics; thin films. Oriental.
P. Bernardini, Simpson, Schein, Thompson, Gell-Mann. Mandel.

Saturday Afternoon

Q. Neutrons, and other topics in nuclear physics. Kent.
R. Arroe; optical and chemical physics. Eckhart.
T. Cryogenics; theoretical physics; Konopinski. Oriental.

PROGRAMME

FRIDAY MORNING AT 10:00

Mandel Hall

(A. W. LAWSON presiding)

Semiconductors

A1. On the Electrical Conductivity of Graphite. G. K. HORTON* AND G. E. TAUBER,† *National Research Council, Canada.*—The electrical conductivity of graphite has been calculated in the layer approximation using the Lukesh-Pauling stacking of graphite. This stacking is distinguished from the older Bernal stacking, in the layer approximation,[1] by the fact that the individual carbon atoms are no longer situated at the corners of *perfect* hexagons. The band structure is given using the Bloch (tight binding) approximation. The existence of an energy gap at the corners of the Brillouin zone is established and its magnitude calculated. Graphite has one conduction electron per atom in the $2p$ state. This is described by a wave function of the form $z(ae^{-\alpha r}+be^{-\beta r})$, where the constants a, b, α, β, have been matched against the known numerical values of the $2p$ wave functions calculated by Jucys for the $^5S_0$ (quadrivalent) state of the carbon atom. By assuming a *heuristic* lattice potential with adjustable parameters, it has been possible to make reasonable estimates of the various parameters (overlap integrals) occurring in the theory. Finally, the electrical conductivity has been calculated and compared with the experimental and the theoretical (Wallace) results based on the usual Bernal stacking. The conductivity is found to be an order of magnitude too small.

* On leave of absence from the University of Alberta.
† National Research Laboratories Postdoctorate Fellow.
[1] The three-dimensional case is also considered and it is shown that the main features of the layer approximation are preserved.

A2. Conduction Properties of *P*-Type Germanium between 25 C and 925 C. W. C. DUNLAP, JR., D. E. MCMILLAN, AND R. A. BROOKS, *General Electric Research Laboratory.*—A study has been made of three p-type single crystals of germanium between 25 C and 925 C. The samples had resistivities of 1.5, 0.2, and 0.005 ohm cm. Hall coefficient, resistivity, and mobility were determined. The theory of intrinsic conduction was applied to obtain the values of hole and electron mobilities and their variations with impurity content and temperature. The best fit was obtained with a variable parameter C (between 0.5×10^{32} and 5.0×10^{32}) in the equation $n_i^2 = CT^3\exp(-\Delta E/kT)$, where n_i is the density of intrinsic electrons and ΔE is the band gap. The room temperature hole mobilities were 2300, 1700, and 400 cm²/volt sec. and varied as T^{-n}, where n was 1.9, 1.7, and 1.5, respectively. The electron mobility was the same for all samples, and varied as T^{-2}. All the data were described satisfactorily using a band gap 0.72 ev. Between 900 and 925 C there was a sudden drop in Hall coefficient and resistivity, suggestive of incipient melting. It was concluded that a number of properties supposedly characteristic of the lattice itself are strongly affected by extremely dilute concentrations of impurities.

A3. Infrared Absorption Photoconductivity and Impurity States in Germanium.* W. KAISER AND H. Y. FAN, *Purdue University.*—Measurements of infrared absorption and photoconductivity were made on germanium containing gold and copper as impurities. Electrical data gave an acceptor activation energy of 0.21 ev for the gold-doped sample. Photoconductivity at liquid nitrogen and liquid helium temperatures showed a threshold at 6 microns in good agreement with the impurity activation energy. At 300°K the absorption coefficient beyond 7 microns agreed with values for other p-type germanium of the same hole concentration.[1] At 77°K, where the hole concentration became very small, only lattice absorption remained beyond 3 microns. Coppered-doped germanium was prepared by heating the sample with copper deposit on the surfaces at elevated temperatures, followed by quenching. The p-type sample had a hole concentration of 2×10^{16} cm^{-3} and an acceptor activation energy of 0.052 ev. Both the photoresponse and the absorption at helium temperature showed a maximum around 22 microns, corresponding to this activation energy. At 300°K the absorption beyond 7 microns was again the same as for other p-type samples of comparable hole-concentration. At low temperatures, the absorption decreased smoothly from the maximum toward shorter wavelengths without pronounced minima as observed in other p-type samples. This behavior is consistent with photoionization of acceptors.

* Work supported by the U. S. Signal Corps.
[1] Kaiser, Collins, and Fan, Phys. Rev. **91**, 1380 (1953).

A4. Photoelectric Hall Effect in Germanium Single Crystals. JOHN J. OBERLY, *Sprague Electric Company.*—The potential differences produced in an illuminated semiconductor by a magnetic field were first observed by Kikoin and Noskov[1] and Groetzinger[2] in cuprous oxide, and were interpreted theoretically by Frenkel.[3] The same effect has now been investigated with germanium single crystals. The experimental arrangement is that of the ordinary Hall effect except that the current is produced photoelectrically by illumination of one surface of the sample. The illumination generates electrons and holes which diffuse into the bulk of the sample and are deviated in opposite directions by the magnetic field, causing a photoelectric Hall current or voltage. Since the electrons and holes recombine on their way through the sample, the photoelectric Hall effect decreases with increasing distance from the illuminated surface at a rate given by the bulk life time of minority carriers. The variation of the photoelectric Hall effect across the surface of the sample will be discussed as function of magnetic field (up to 26 kilogauss), light intensity (up to 12 lumens/cm²) from a tungsten filament lamp), and resistivity of the germanium sample.

[1] I. K. Kikoin and M. M. Noskov, Physik. Z. Sowjetunion **5**, 586 (1934).
[2] G. Groetzinger, Physik. Z. **36**, 168 (1935).
[3] J. Frenkel, Physik. Z. Sowjetunion **5**, 597 (1934).

A5. Low-Temperature Recombination and Trapping in Germanium.* D. NAVON AND H. Y. FAN, *Purdue University.*—The lifetime of injected carriers was determined for P-type germanium from 300°K to 100°K. It decreases with decreasing temperature, rapidly at first, then more slowly. In some N-type samples the determination of the hole-electron recombination rate at low temperatures is complicated by the presence of traps,[1] which are found to be distributed through the sample volume. The recombination rate may be determined by an experiment in which a steady state with respect to the traps is established so that recombination will proceed as in the absence of traps. Using dc emitter current and long-pulse sweep-

ing field, the product of the minority carrier lifetime and mobility was obtained from the dependence of the steady-state collector current on the sweep voltage. The mobility was obtained by an independent measurement, in which the sample is flooded with light to saturate the traps. The variation of recombination rate with temperature for this *N*-type sample was similar to that of the *P*-type sample, whereas the excess conductivity caused by trapped carriers disappeared with *increasing* time constant as the temperature decreased.

* Work supported by a U. S. Signal Corps contract.
[1] D. Navon and H. Y. Fan, Phys. Rev. **91**, 491 (1953).

A6. Magnetic Field Dependence of Hall Coefficient in InSb.* R. K. WILLARDSON, A. C. BEER, AND A. E. MIDDLETON, *Battelle Memorial Institute.*—The dependence of the Hall coefficient on magnetic field can be described in terms of a dimensionless parameter involving the product of the applied magnetic field and the carrier mobility in the semiconductor.[1] Since in InSb the electron mobility is approximately 20 times that in germanium, it is expected that variations in the Hall coefficient could occur even at weak magnetic fields. Changes in Hall coefficient with magnetic field were determined over the temperature range from 80° to 700°K for both *N*- and *P*-type specimens. Of especial interest are the results for the *P*-type specimens in which the Hall coefficients determined at fixed temperatures may vary by several orders of magnitude and even change sign. This occurs because of variations in the temperatures at which the crossover points and the maxima occur for different magnetic fields. However, significant variations in the magnitudes of the maxima are also observed. These results, as well as the magnitudes of the effects observed in the intrinsic regions, appear consistent with theoretical predictions.

* Supported by Wright-Patterson Air Force Base, Ohio.
[1] V. A. Johnson and W. J. Whitesell, Phys. Rev. **89**, 941 (1953).

A7. Degeneracy in High-Purity InSb.* A. C. BEER, R. K. WILLARDSON, AND A. E. MIDDLETON, *Battelle Memorial Institute.*—The forbidden zone in pure InSb is quite narrow, approximately 0.28 ev at 77°K and decreases significantly with increasing temperature, being approximately 0.18 ev at 300°K.[1] Consequently, a Fermi level in intrinsic InSb midway between the bands would be within 4 kT of the conduction band at 300°K. Furthermore, in intrinsic InSb, resulting from the large ratio of hole-to-electron effective masses indicated by unusual electron-hole mobility ratios and substantiated by thermoelectric power measurements, the Fermi level is actually raised significantly above the mid-point. Consequently, for calculations at high temperatures, the classical expressions should be replaced by Fermi-Dirac functions. It also follows that the relatively low effective electronic mass causes even fairly high-purity *N*-type specimens to be degenerate at all temperatures. For *P*-type specimens, however, the classical approximations appear adequate at intermediate temperatures. The use of the singular points of the Hall and thermoelectric power curves to evaluate parameters of such specimens is discussed.

* Supported by Wright-Patterson Air Force Base, Ohio.
[1] M. Tanenbaum and H. B. Briggs, Phys. Rev. **91**, 1561 (1953).

A8. Temperature Dependence of Transverse Magnetoresistance Effect in InSb.* T. C. HARMAN, R. K. WILLARDSON, AND A. C. BEER, *Battelle Memorial Institute.*—Transverse magnetoresistance effects were determined from 80°K to 700°K for both *N*- and *P*-type specimens of InSb. The magnitude of the effect for the *N*-type material was quite low. The *P*-type specimens, on the other hand, exhibited as a function of temperature magnetoresistance maxima at which unusually large values were observed. These maxima occurred at temperatures near those at which the Hall coefficients also exhibited maxima. With increasing magnetic field, these maxima shifted to higher temperatures, as was also true for the Hall coefficients. For a *P*-type specimen containing 1.5×10^{16} ionized acceptors per cc, a value of 1.3 for $\Delta\rho/\rho_o$ was observed at 270°K for a magnetic field of 8000 gauss. The variation of $\Delta\rho/\rho_o$ with field was linear between 3500 and 8000 gauss, with no indications of saturation. As the temperature was increased to a point where the conduction was essentially intrinsic, the magnetoresistance values for specimens of various impurity concentrations, including the *N*-types, approached a common value, as would be expected. For example, a value of 0.08 for $\Delta\rho/\rho_o$ was observed at 650°K and 8000 gauss.

* Supported by Wright-Patterson Air Force Base, Ohio.

A9. Optical Properties of Some Group III-Group V Compounds. H. B. BRIGGS, R. F. CUMMINGS, H. J. HROSTOWSKI, AND M. TANENBAUM, *Bell Telephone Laboratories.*—Infrared spectra of the semiconducting compounds InSb, GaSb, AlSb, InAs, and GaAs have been observed. The antimonides were prepared by melting together stoichiometric amounts of the components. The arsenides were prepared by heating stoichiometric amounts of the elements above the melting point of the compound in sealed quartz tubes with continual shaking of the mixture. Grain sizes of the compounds were sufficiently large to give good transmission in the infrared. Except for the anomalous behavior reported for InSb,[1] optical activation energies have been directly determined. Refractive indexes of these compounds have been measured with a Gaertner spectrometer by the prism method as described by H. B. Briggs.[2] A modification of this technique was used for InSb. It has been suggested[3] that the relation $E\epsilon^2$=constant holds for the semiconducting elements of Group IV where ϵ is the dielectric constant and E the activation energy. This equation is obeyed reasonably well by these intermetallic compounds with the exception of InSb.

[1] M. Tanenbaum and H. B. Briggs **91**, 1561 (1953).
[2] H. B. Briggs, Phys. Rev. **77**, 287 (1950).
[3] T. S. Moss, *Photoconductivity in the Elements* (Butterworths Scientific Publications, London, 1952).

A10. Magnetoresistance in InSb and GaSb Single Crystals. M. TANENBAUM, G. L. PEARSON, AND W. L. FELDMANN, *Bell Telephone Laboratories.*—The magnetoresistance of polycrystalline InSb has been studied by Pearson and Tanenbaum[1] and by Weiss.[2] Similar measurements have now been performed on oriented single crystals of both InSb and the analogous compound GaSb. The preparation of single crystals by zone-refining and crystal pulling will be described. Crystals of *n*- and *p*-type InSb and *p*-type GaSb were studied. With current flowing along either the 100- or 110-crystal direction, the magnetoresistance was measured as a function of magnetic field strength, field orientation, and as a function of temperature from 78°K to 300°K. The variation of magnetoresistance with magnetic field orientation shows the same simple behavior in the single crystals of InSb and GaSb as was previously reported for polycrystalline InSb. These results are in agreement with the theory of the magnetoresistance effect based on the assumption of spherical energy surfaces. In GaSb the hole mobility at 300°K is 1000 cm²/volt sec for magnetoresistance and 700 cm²/volt sec from Hall effect, and both mobilities show the same temperature dependence. In InSb the relationship is more complex because of the reversal in sign of the Hall constant at about 200°K.

[1] G. L. Pearson M. Tanenbaum, Phys. Rev. **90**, 153 (1953).
[2] H. Weiss, Z. Naturforsch. **8a**, 463 (1953).

A11. Some Analogies between Lattice Defects and Current Carriers in Semiconductors. J. ROTHSTEIN, *Signal Corps Engineering Laboratories.*—Except for differences in statistics, Frenkel defects are analogous to hole-electron pairs, Schottky

defects to extrinsic carriers. Defect analogies exist for impurity carriers, trapping, injection, impurity cancellation, and perhaps breakdown. Near any insterstitial atoms or near large substitutional impurities, lattice strain reduces Frenkel activation energy and tends to trap vacancies, thus donating interstitials or accepting vacancies. Small impurities are vacancy donors or interstitial acceptors. Impurities should thus enhance diffusion as they do conductivity, large and small impurity effects should cancel (like $n-p$ cancellation), intense local stress should generate defects like carrier injection in high fields (compressive: interstitial free, vacancy trapped; tensile: vacancy free, interstitial trapped), photoinjection of pairs is analogous to bombardment defects, decay of injected conductivity to relaxation processes, stress induced migration to electrical conductivity, orientation of adjacent impurities of different size in stress fields to dipole orientation, and perhaps dielectric breakdown to fracture and Zener current to slip. The analogies are of particular interest for semiconductors, where vacancies are acceptors and interstitials donors, and defects and carriers are linked through deformation potentials and the phonon field.

A12. Capacity Measurements on Point Contact Germanium Diodes. MAYNARD DAWSON AND GEORGE FINN, *Sylvania Electric Products, Inc.*—Measurements of capacity as a function of reverse applied voltage have been carried out on high-peak inverse voltage germanium point contact rectifiers. Description of the measuring apparatus and techniques is given. The capacity measured was about 0.4$\mu\mu$f at 5 volts applied reverse bias, decreased to a value of the order of 0.01 $\mu\mu$f at values of between 20 volts and 30 volts reverse bias, and remained constant within experimental error over the remaining range of measurements. A model of the reverse barrier of point contact diodes is proposed, and the dependence of the capacity of the barrier upon applied reverse voltage which is calculated from this model is compared with the experimental results.

A13. A New Galvanomagnetic Effect. I. Theory. COLMAN GOLDBERG, *Westinghouse Research Laboratories.*—Using the following equation[1] for the electrical field in a cubic crystal carrying an electric current i in the presence of a magnetic field H,

$$E=\rho_0[i+ai\times H+biH^2+cH(i\cdot H)+dMi],$$

we can deduce that for the experimental conditions $i_y=i_z=H_x=0$ the electric field in the y direction is $\rho_0 c i_z H_x H_y$. Thus the coefficient c can be evaluated experimentally and can be used to check values for this coefficient obtained from magnetoresistance experiments.[1] Theoretical evaluation of c using certain simplifying assumptions[2] shows that c and, hence, measurements of this new effect can be used to calculate the carrier mobility which should be equal to the mobility calculated from Hall measurements.

[1] G. L. Pearson and H. Suhl, Phys. Rev. **83**, 768 (1951).
[2] F. Seitz, Phys. Rev. **79**, 372 (1950).

A14. A New Galvanomagnetic Effect. II. Experiments with Germanium. R. E. DAVIS AND COLMAN GOLDBERG, *Westinghouse Research Laboratories.*—Working with single crystals of germanium we have found that for $i_y=i_z=H_z=0$ the voltage in the y direction can be represented by

$$V_y=Gi_zH^2\sin 2\psi,$$

where ψ is the angle between H and the x axis. This is in agreement with the theory presented in the preceding paper. Care must be taken to eliminate a voltage caused by the Hall effect. This Hall voltage appears if the magnetic field does not lie precisely in the xy plane and, hence, $H_z\neq 0$. The coefficient c and the mobility μ are calculated from the coefficient G of the above equation.

FRIDAY MORNING AT 10:00

Kent 106

(J. A. SIMPSON presiding)

Cosmic Rays; Particles Other Than Pi-Mesons

B1. Cosmic-Ray Ionization Bursts in an Eight-Inch Sphere at Sea Level. H. CARMICHAEL AND J. F. STELJES, *A.E.C.L. Chalk River Laboratory.*—The complete size-frequency distribution curve of ionization bursts in an 8-inch diameter spherical steel ion-chamber, with a 1/16-in. thick wall containing argon at 50 atmos pressure, has been carefully measured in 4500 hours of observation at sea level. The sizes of the bursts range from 4×10^4 to nearly 10^8 ion-pairs and the corresponding frequencies from 2×10^4 to 2×10^{-4} per hour. Plotted in the conventional double logarithmic manner the size-frequency distribution appears to involve three clearly separable components. One component corresponds closely to the bursts expected from the known number of single μ mesons and single electrons that intersect the ion-chamber, including the Landau-Symon fluctuation of size: another corresponds to the bursts expected from the extensive air showers as measured by counters. The third component, comprising bursts of intermediate size, evidently results mainly from the nucleon component of the cosmic radiation and an attempt is being made to measure separately the contributions from the known nucleon events; stars, single protons and heavier particles, penetrating showers, etc.

B2. The Influence of Lead Shielding on Ionization Bursts at Sea Level. J. F. STELJES AND H. CARMICHAEL, *A.E.C.L. Chalk River Laboratory.*—Bursts in the ion-chamber described in the preceding paper have been measured with close fitting lead hemispheres of various thicknesses between 0.3 cm and 17 cm above the ion-chamber. Bursts of size between 4×10^4 and 10^5 ion-pairs diminish in number in the first centimeter of lead by slightly more than 20 percent and thereafter with increasing thickness diminish in number only a further 20 percent. This behavior is consistent with the rapid replacement of the single electrons by cascade showers which cause bursts of larger size, the single mesons being much more slowly absorbed by the lead. In the region of intermediate burst sizes the transition curve has a sharp maximum, the size and shape of which changes progressively with burst size. The largest bursts, in the 5×10^6 to 10^8 ion-pair range of size, increase in number slowly at first and then rapidly to 100 times their number in the unshielded ion-chamber and thereafter this rate appears to be maintained with increasing thickness of lead. Lead placed underneath the unshielded ion-chamber has practically no effect on the bursts.

B3. Cross Section for Trident Production by Electrons of the Cosmic Radiation. W. W. WADA AND D. T. KING, *Naval Research Laboratory.*—Among ~200 tridents—direct production of electron pairs by charged particles of great energy—we have been able to determine in 67 cases the energy of the incident particle. Fourteen of these have primary energy between 10^2–10^4 Mev and originate on one arm of an electron pair starting in the emulsion. In the same volume the total length of electron track arising from pair creation is found to be 1340 ± 350 cm. The cross section for trident production by electrons of mean energy 1 Bev is thus $(1.3\pm0.5)\times10^{-26}$ cm^2. This result is in agreement with the theoretical prediction of Racah[1] but is smaller than that of Bhabha,[2] in contrast to a recently reported[3] determination at higher energies.

[1] G. Racah, Nuovo cimento **14**, 93 (1937).
[2] H. J. Bhabha, Proc. Roy. Soc. (London) **A152**, 559 (1935).
[3] J. E. Naugle and P. S. Freier, Bull. Am. Phys. Soc. **28**, No. 5 (1953).

B4. Charged Particles Intermediate in Mass Between Protons and Deuterons. M. M. SHAPIRO, D. T. KING, AND N. SEEMAN, *Naval Research Laboratory.*—Two examples of singly charged particles with masses $2560\pm500\ m_e$ and $2980\pm850\ m_e$, respectively, are described. The phenomenological aspects and methods of measurement are different for the two "hyperons." The first is a track 18.6 mm long, with grain density 2.57 times minimum, which originates in a "fundamental" collision in a G.5 emulsion. The second example presents a track 3.7 mm long, characteristic of a particle arrested by ionization. From its end arises the thin track of an apparent decay particle, of mass $330\pm90\ m_e$. The decay scheme $H^{\pm}\rightarrow V_1^0+\pi^{\pm}+(101_{-15}^{+20})$ Mev is consistent with our observations and yields a computed mass of 2650 m_e. The V_1^0, rather than a secondary neutron, is postulated since a V_1^0 is known to be emitted as a secondary of a charged hyperon.[1] If our observation is correctly identified with the "V-particle cascade," then it follows that the light charged secondary in the latter process is probably a pion.

[1] Anderson, Cowan, Leighton, and Van Lint, Bull. Am. Phys. Soc. **28**, No. 5, (1953).

B5. $K^{\pm}$ Mesons from "Fundamental" Nuclear Collisions. D. T. KING, N. SEEMAN, AND M. M. SHAPIRO, *Naval Research Laboratory.*—A series of measurements on 67 tracks associated with nuclear interactions in photographic emulsions has enabled us to distinguish a group of three particles of mass $1115\pm90\ m_e$, and another particle of $895\pm240\ m_e$. Mass discrimination was enhanced in this study by selecting tracks of adequate length for multiple scattering determination, and having grain densities between 1.3 and 3.0 times the minimum. These grain densities lie well above the insensitive region close to the minimum and below that where serious clumping occurs. The same criteria were applied to the calibration tracks of protons and pions. Of the 67 tracks, 23 were due to the products of "fundamental" collisions as inferred from the absence of evaporation phenomena. Altogether, 4 mesons heavier than the pion, and one hyperon,[1] were observed among these 23, the rest being protons and pions. The remaining 44 tracks, found in the more usual types of stars, were all due to protons and pions.

[1] See preceding abstract by Shapiro, King, and Seeman.

B6. V_0^1 Particle as a High Angular State of Meson-Nucleon System. B. P. NIGAM, *University of Rochester.*—Following Levy, the Salpeter-Bethe equation for the π-nucleon system ($I=3/2$) is reduced to a three-dimensional equation in the adiabatic approximation. This agrees with the equation obtained by Arnowitt and Deser[1] from the relativistic π-nucleon equation[2] derived from Schwinger's Green function method. Their investigation shows the existence of a virtual state of π nucleon at $Q=40$ Mev and angular momentum $L=5$, with a lifetime $\tau=2\times10^{-10}$ sec. In the Tamm-Dancoff formalism, which corresponds to dropping the negative frequency part of the wave function in S-B equation, under similar approximation, a lifetime $\tau=2\times10^{-11}$ sec is obtained for $Q=35$ Mev and $\tau=2\times10^{-10}$ sec for $Q=25$ Mev. The discrepancy in the results arising from the neglect of the negative component seems rather large and the analysis of the problem in the new Tamm-Dancoff formalism proposed by Dyson[3] is in progress.

[1] R. Arnowitt and S. Deser, Phys. Rev. **91**, 459, JA4 (1953).
[2] S. Deser and P. Martin, Phys. Rev. **90**, 1075 (1953).
[3] F. J. Dyson, Phys. Rev. **90**, 994 (1953).

B7. Angular Correlations in τ-Meson Decay. R. H. DALITZ,* *Cornell University* (introduced by H. A. Bethe).—A study of the distribution of 3π-decay configurations in τ-meson decay may lead to some information on the τ-meson spin (j) and parity (w), since the angular correlation between the outgoing π mesons will depend on (j, w). A convenient triangular representation will be described for the specification of τ-meson decay events both (a) when the signs of the π-meson charges are known and (b) when they are not, and the available data on τ-meson decay will be displayed in this representation. The distribution of decay configurations may be estimated for given (j, w) by considering only those outgoing π-meson waves of lowest allowable angular momenta and some typical cases will be compared with the data. The distributions following from some more specific τ-meson models will also be presented. Data of type (a) will clearly have a far more sensitive dependence on (j, w) and other τ-meson properties than the more common data of type (b). The possible effects of strong interactions between π-mesons on the distribution of decay configurations will be mentioned and their possible identification considered.

* On leave of absence from Department of Mathematical Physics, University of Birmingham, England.

B8. The Light Elements of the Cosmic Radiation—Experimental.* G. W. RACETTE, M. F. KAPLON, AND D. M. RITSON,† *University of Rochester.*—A stack of 27–250μ Ilford emulsions on glass was flown with vertical orientation for 8 hours at White Sands, N. M. ($\lambda=41°$) at a mean depth of 20 g; the 27 plates consisted of 9 triads of G-5, C-2, and D-1 emulsions. The G-5 emulsions were scanned for all tracks with $I>6I$ min and with projected length $>725\mu$. All tracks obtained were traced as far as possible through the stack, the variation of I with range being used to differentiate tracks with $Z\geq3$ from nonrelativistic α particles, slow protons, and deuterons. Charge determination was made by gap density and grain count in the insensitive emulsions. In a survey of 15 cm^2 of emulsion we have found 21 particles with $3\leq Z\leq5$ (L nuclei), 26 with $6\leq Z\leq10$ (M nuclei), and 8 with $Z>10$ (H nuclei). The primary flux values obtained for M and H nuclei are in accord with values previously reported.[1]

* This research was supported in part by the U. S. Air Force.
† Now at Massachusetts Institute of Technology, Cambridge, Massachusetts.
[1] Kaplon, Peters, Reynolds, and Ritson, Phys. Rev. **85**, 295 (1952).

B9. The Light Elements of the Primary Cosmic Radiation—Interpretation.* M. F. KAPLON, G. W. RACETTE, AND D. M. RITSON, *University of Rochester.*—To analyze the preceding data we have considered the diffusion equations for the three charge groups (L, M, H). Besides the depth of observation, the solutions depend upon λ_I (interaction mean free path) and P_{I-J} (probability of J-type production when an I type interacts) which are not well known for atmosphere (particularly P_{I-J}). It is necessary in our experiment to sum over all zenith angles consistent with our scanning criteria. Letting α be the calculated ratio of observable L nuclei emerging from collisions in the residual atmosphere to observable M nuclei with our scanning criteria, we find $\alpha=0.35$; 0.61 for $P_{ML}=0.23$; 0.40[1], respectively; if, for $P_{ML}=0.40$, λ_L is increased by 10

percent, $\alpha=0.69$. Thus, the interpretation of the observed ratio $L/M=21/26=0.81$ depends on the λ_I and P_I. Though our observations differ markedly with those of Bradt and Peters[2] and tend to confirm those of the Bristol Group,[3] we believe that a primary flux value of L nuclei derived by extrapolation cannot yet be unequivocally given, though at present the evidence favors the existence of some primary flux of the light elements. $(0.10 \lesssim L_0/M_0 \lesssim 0.5)$.

* The research was supported in part by the U. S. Air Force.
[1] J. H. Noon (private communication); the value 0.40 is derived from an analysis of heavy nuclei interactions in emulsion. $P_{\pi I}=0.23$ is used in references 2 and 3.
[2] H. Bradt and B. Peters, Phys. Rev. **80**, 943 (1950). They find $L_0/M_0 < 0.1$.
[3] Dainton *et al.*, Phil. Mag. **43**, 729 (1952). They find $L_0/M_0 \sim 1$.

B10. Search for the Production of μ-Meson Pairs by 340-Mev Bremsstrahlung.* A. WATTENBERG, B. T. FELD, A. JULIAN, A. ODIAN, AND L. S. OSBORNE, *M.I.T.*—A search is in progress for the production of $\mu^+\mu^-$ meson pairs by the 340-Mev bremsstrahlung from the M.I.T. synchrotron. Special detectors and electronics were constructed for this experiment and will be described. At the time of the submission of this abstract, it has been established that the cross section for the production of μ-meson pairs is less than 2×10^{-31} cm^2 per equivalent quanta. This value is based on runs with beryllium as a target with two detectors at 90° to the x-ray beam.

* This work was supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

B11. A Pure Negative Muon Beam. LESTER WINSBERG, *University of Chicago.*—The 102 Mev π^- beam from the Chicago synchrocyclotron contains approximately 20 percent negative muons as shown by a range curve in copper. The beam is cleansed of neutral and positive particles by means of a 45° deflecting magnet. The pions are removed by placing a graphite filter, 36.0 g/cm^2 thick, against the end of the magnet pole-piece facing the synchrocyclotron. The purity of the beam was tested by irradiating one kilogram of iodine against the other end of the pole-piece. A copper plate one-half inch thick was placed in front of the sample for the maximum number of muon endings to occur in the sample. The absence of 6*d* Te^{118}, which is produced in relatively high yield by pions,[1] demonstrated the purity of the beam. The presence of 9.3*h* Te^{127} from the reaction $I^{127}(\mu^-, \nu)$ and examination of track endings in photographic plates demonstrated that the beam indeed consisted of negative muons.

[1] L. Winsberg, Phys. Rev. **90**, 343(A) (1953).

FRIDAY MORNING AT 10:00

Eckhart 133

(L. M. LANGER presiding)

Beta Emitters

C1. End-Point Energy Determination of Beta Emitters.* M. FORRO, *Evanston, Illinois.*—It was found that the absorption of beta spectra in materials of high atomic number is exponential and the absorption coefficients in gold are inversely proportional to the 3/2 power of the end-point energy of the spectrum. This experimental law holds with 2 percent accuracy in the energy-interval from 0.3 Mev to 2.2 Mev; and in the intensity domain from ½ to 1/100 of the original intensity, if a detector with small opening is used. The end-point energy of beta emitters can be, therefore, determined by measuring only two points on a gold absorption curve and is expressed by the equation, $E=9\mu^{-1}+0.017$, with 2 percent accuracy from 0.17 Mev to 2.2 Mev, where E is the end-point energy in Mev, and μ the absorption coefficient in gold in cm^2/g. The results obtained on 12 isotopes, and the influence of certain factors and a semi-automatic equipment for the determination of the end-point energies will be discussed.

* Research supported by Frederick Gardner Cottrell grant of Research Corporation.

C2. Positron-Capture Branching Ratios.* PAUL F. ZWEIFEL, *Knolls Atomic Power Laboratory.*—First-forbidden correction factors for K and L capture have been calculated for the five invariant interactions and linear combinations. Also, the effect of screening on first-forbidden positron spectra has been calculated, the screening corrections being essentially identical with those given by Reitz[1] for allowed spectra. Branching ratio analyses of Zn^{65}, Na^{22}, and V^{48} were made. Assuming, as predicted by the shell model, an L forbidden $\Delta J=1$, $\Delta L=2$ transition for Zn^{65}, agreement with experiment was obtained. If screening is neglected, the theoretical branching ratio is outside experimental limits. The Na^{22} spectrum has an allowed shape but can also be fitted by a first-forbidden tensor interaction[2] with $\int\beta\alpha = -2.25\int\beta\sigma\times\mathbf{r}$. The latter yields a branching ratio close to the theoretical allowed ratio, so in view of the lack of experimental data, no choice can be made between the two possible degrees of forbiddenness. For V^{48}, the linear combinations discussed by Pursey[2] were investigated. The following interactions give both linear Kurie plots and reasonable branching ratios: Allowed; first forbidden, $\Delta J=1$, $T+Y_sS$ or $T+Y_vV$, where $1/16 \lesssim Y_s \lesssim 1/4$ or $1/6 \lesssim Y_v \lesssim 1/2$. Pursey's method for estimating nuclear matrix elements was used.

* Based on author's Ph.D. thesis to be submitted to Duke University Graduate School.
[1] J. R. Reitz, Phys. Rev. **77**, 10 (1950).
[2] D. L. Pursey, Phil. Mag. **42**, 1193 (1951).

C3. Methane Proportional Counter Method for C^{14} Age Determinations. W. H. BURKE, JR., AND W. G. MEINSCHEIN, *Magnolia Petroleum Company.*—A method has been developed for making C^{14} age determinations on samples containing 0.8 gram of carbon by conversion to methane and counting the C^{14} beta radiation in a proportional counter filled with the sample methane. The sample is burned to get the carbon in the form of CO_2. The CO_2 is purified and then converted to methane by circulating it with an excess of hydrogen over a hot ruthenium catalyst. After excess hydrogen is removed, the methane is entered into the counter at 2 atmospheres absolute pressure. The counter is operated at 3500 volts in the center of the proportional plateau which is 600 volts in length and has a slope of less than 1 percent per hundred volts. The counter is surrounded by anticoincidence cosmic counters and eight inches of iron in the manner described by Anderson, Arnold, and Libby.[1] The counting rate with a modern organic sample in the counter is eight counts per minute over background. Thus about two thirds of the beta particles from the C^{14} in the counter are being counted. There is good reason to believe that this counting efficiency can be considerably improved.

[1] Anderson, Arnold, and Libby, Rev. Sci. Instr. **22**, 225 (1951).

C4. Inner Bremsstrahlung from P^{32}. MAX GOODRICH AND WILBUR B. PAYNE, *Louisiana State University.*—The inner bremsstrahlung from P^{32} has been measured[1-3] from 3 to 240 kev and found to agree satisfactorily with theory[4] for an allowed beta spectrum. The authors have extended the measurements to 900 kev, using a NaI scintillation spectrometer. By using different beta-ray absorbers, the contribution of external bremsstrahlung to the data was found to be of the order of a few percent. Applying the crystal's known response curve to the theoretical spectrum, and normalizing at one energy, the data and calculations have been found to agree within 10 percent from 75 to 900 kev.

[1] T. B. Novey, Phys. Rev. **89**, 672 (1953).
[2] Bolgiano, Madansky and Rasetti, Phys. Rev. **89**, 679 (1953).
[3] G. A. Renard, J. Phys. et radium **14**, 361 (1953).
[4] C. S. Wang Chang and D. L. Falkoff, Phys. Rev. **76**, 365 (1949).

C5. The Disintegration of Co^{55}. R. S. CAIRD AND ALLAN C. G. MITCHELL, *Indiana University.**—The spectrum of Co^{55} (18 hr) has been investigated with the help of a magnetic lens spectrometer, coincidence lens, a 180° magnetic spectometer, and scintillation counters. The decay scheme of Deutsch and Hedgran[1] has been found to describe the main features of the decay but certain new positron groups and gamma-ray lines have been found, which make the scheme more complicated than originally supposed. Positron groups are found at 1.508 Mev (53 percent), 1.00 Mev (40 percent), 0.53 Mev (5 percent), and 0.26 Mev (2 percent). Gamma rays of 0.477, 0.935, 1.41, 0.251, 1.78, and 2.24 Mev have been found. The last three are very weak. A disintegration scheme will be presented.

* Supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] M. Deutsch and A. Hedgran, Phys. Rev. **75**, 1443 (1949).

C6. Decay Scheme of Se^{75} and Ge^{75}.* A. W. SCHARDT AND JOAN P. WELKER, *Brookhaven National Laboratory.*—The energy levels of As^{75} have been investigated using Se^{75} and Ge^{75} sources, a scintillation spectrometer, and gray wedge coincidence analyzer.[1] The results are summarized in Table I.

TABLE I.

Transition energy (kev)[a]	Se^{75} data: $\gamma-\gamma$ coincidences	Se^{75} data: Rel. intensities	Ge^{75} data: $\gamma-\gamma$ coincidences	Ge^{75} data: Rel. intensities
405	None	0.17 ±0.02		<0.02
281	124	1.00		
269	138		None	1.00
203	67, 138(?)	~0.021	67	~0.11
138	67, 269	0.84 ±0.10		
124	281			
98		~0.036		
76		<0.002		
67	138, 203	~0.012	203	observed

[a] Taken from Jensen, Laslett, Martin, Hughes, and Pratt, Phys. Rev. **90**, 557 (1953).

In addition, the 269-kev line from Ge^{75} is in coincidence with an 11.2±1.0 percent beta branch, the end-point of which is ~250 kev below that of the main beta group. It may be concluded that the 405-, 269-, and 203-kev lines are transitions to the ground state of As^{75}.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Chase, Bernstein, and Schardt, Phys. Rev. **90**, 353 (1943).

C7. The Gamma Spectra of Cd^{117} and In^{117}. J. M. LEBLANC, J. M. CORK,* AND S. B. BURSON, *Argonne National Laboratory.*—The gamma spectra of Cd^{117} and In^{117} have been studied with 180° photographic spectrometers and with a 10-channel coincidence scintillation spectrometer. Sources were obtained by irradiating enriched Cd^{116} in the Argonne heavy water reactor. Internal conversion electrons associated with 0.160-, 0.267-, 0.281-, and 0.312-Mev gamma rays were observed. In addition to these, transitions of energy 0.43, 0.55, 0.72, 0.84, 1.27, 1.55, and 2.00 Mev were detected with the scintillation spectrometer. The decay of each peak has been followed. Chemical separations of the In from the Cd were made and the spectra of each fraction studied with the scintillation spectrometer. Then 0.160-, 0.312-, 0.55-, and 0.72-Mev gamma rays are associated with the In fraction, and all decay with a 2.3-hour half-life. The remaining gamma rays are in the Cd fraction. The 0.312-Mev gamma ray is the most strongly converted, and, furthermore, is not in coincidence with beta-rays. It is interpreted as an isomeric transition in In^{117}. Results of beta-gamma and gamma-gamma coincidence measurements will be discussed.

* University of Michigan.

C8. Disintegration of the 10-Year Ba^{133}. R. W. HAYWARD, D. D. HOPPES, AND H. ERNST, *National Bureau of Standards.*—The radiations from the 10-year K-capturing Ba^{133} activity have been investigated using scintillation pulse height and coincidence counting techniques. A low specific activity source of $Ba(NO_3)_2$ was used, the material having been irradiated in the Oak Ridge pile and subsequently aged for eighteen months. Four gamma rays were observed with the following energies and intensities per disintegration: 57 kev (0.01), 82 kev (0.22), 300 kev (0.31), and 357 kev (0.69), where the probable errors in the energy are approximately one percent. Coincidences were observed between the 357- and 82-, 300- and 82-, 300- and 57-, and 82- and 57-kev gamma rays, but none were observed between the 300- and 357- or the 357- and 57-kev gamma rays. From the observed intensities and the assumed disintegration scheme, the conversion coefficient of the 82-kev transition was found to be $\alpha = 3.5$ which is consistent with a magnetic dipole. A level scheme in Cs^{133} consistent with the experimental evidence is as follows: ground level, g 7/2; 82-kev level, d 5/2; 382-kev level, d 3/2; and 439-kev level, s 1/2. The K-capture branching is such that 75 percent of the transitions go to the 439-kev level and 25 percent to the 382-kev level.

C9. Transmission of 0–50 Kilovolt Electrons by Thin Films With Applications to Beta Spectra.* R. O. LANE AND D. J. ZAFFARANO, *Iowa State College.*—Electron transmission curves have been obtained for aluminum-coated plastic films of 24–630μg/cm^2 surface density by the use of an electron accelerating tube and a Faraday collector. Good agreement was found with the range-energy data of Schonland[1] whose thinnest film was ~250μg/cm^2 aluminum. The comparison between the measured ranges and those predicted by energy-loss theory and by the extrapolation of empirical relations will be discussed. A vacuum-distilled $Pm^{147}Cl_3$ source of ~0.2 μg/cm^2 on a 6μg/cm^2 collodion backing was examined in a thin lens beta-ray spectrometer employing a G-M counter having one of the above films (320μg/cm^2) as a side window. Assuming that the true Fermi plot for Pm^{147} is linear, application of the measured window transmission curve to these data gave an apparent overcorrection by a maximum of 4 percent at 14 kev. This is probably caused by the unavoidable slight difference in the solid angle subtended by the Faraday collector and the G-M tube.

* This work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
[1] B. F. J. Schonland, Proc. Roy. Soc. (London) **A108**, 187 (1925).

Invited Papers

C10. The Influence of Extra-Nuclear Fields on the Angular Correlation of Nuclear Radiation. R. M. STEFFEN, *Purdue University.* (30 min.)

C11. The Influence of the Electric Quadrupole Interaction on Angular Correlation. T. B. NOVEY, *Argonne National Laboratory.* (15 min.)

FRIDAY MORNING AT 10:00

Oriental Institute

(R. ROLLEFSON presiding)

Invited Papers

D1. Interactions of Fast Neutrons with Heavy Nuclei. H. H. BARSCHALL, *University of Wisconsin.* (30 min.)

D2 and D3. Capture of Polarized Neutrons by Polarized Mn-55 and Sm-149 Nuclei: (a) Production of the Nuclear Polarization, (b) Observation of Effects Due to Nuclear Polarization. L. D. ROBERTS AND SEYMOUR BERNSTEIN, *Oak Ridge National Laboratory.* (40 min, to be divided between the two.)

FRIDAY AFTERNOON AT 2:00

Mandel Hall

(R. W. THOMPSON presiding)

Invited Paper

F1. Pion-Hydrogen Scattering. ENRICO FERMI, *University of Chicago.* (45 min.)

Pi-Mesons

F2. Internal Conversion of Mesic γ Rays.* C. P. SARGENT, M. C. RINEHART, R. C. CORNELIUS, L. M. LEDERMAN, AND K. ROGERS, *Columbia University.*—The Nevis 17-in. diffusion cloud chamber has been employed to observe negative pions stopping in hydrogen gas. Thirty events were recorded in which electron pairs were associated with stopped pions. 3800 stopped pions were counted. Momentum analysis in the 7800-gauss magnetic field showed that 19 of the events correspond to the reaction $\pi^- + P \rightarrow \pi^0 + N$, $\pi^0 \rightarrow e^+ + e^- + \gamma$, and 11 of the events correspond to $\pi^- + P \rightarrow N + e^+ + e^-$. These lead to conversion coefficients of 0.0055 for the π^0 decay and 0.0057 for the radiative reaction. This assumes a branching ratio of 0.90 for the mesic to radiative absorption rates. The angular correlation and energy distribution of the π^0 pairs agree well with theory.[1] The same pictures are being used to measure the momentum distribution of electrons arising from the decay of negative μ mesons.

* This work was performed under the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Dalitz, Proc. Phys. Soc. (London), **A64**, 667 (1950).

F3. Mass Difference of Neutral and Negative π Mesons.* W. CHINOWSKY, A. SACHS, AND J. STEINBERGER, *Columbia University.*—A measurement has been performed on the angular correlation of the γ-ray pair from the decay of π^0 mesons produced by the interaction of π^- mesons stopped in liquid hydrogen. The deviation of the correlation from 180° is a measure of the π^0 velocity and therefore can be used to determine the $\pi^- - \pi^0$ mass difference. Analysis of our results yields for the π^0 velocity $v/c = 0.200 \pm 0.009$ and $m_{\pi^-} - m_{\pi^0} = 8.8 \pm 0.6\ m_e$, in agreement with the earlier result of Panofsky,[1] $10.6 \pm 2\ m_e$.

* This work was performed under the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.
[1] Panofsky, Aamodt, and Hadley, Phys. Rev. **81**, 565 (1951).

F4. The Energy Spectrum of Negative Pions Produced in Be by 2.3-Bev Protons.* S. J. LINDENBAUM AND LUKE C. L. YUAN, *Brookhaven National Laboratory.*—Preliminary results for the energy spectrum of negative pions emitted at 32° (laboratory angle) from a 2×2×6-inch beryllium target bombarded by 2.3-Bev protons have been obtained. The experimental arrangement was similar to that previously described.[1] A 3-inch collimator looked directly at the beryllium target (in a straight section outside the magnet quadrant) at an angle of 32° from the incident beam direction. A double coincidence counter telescope defined and minotored the incident beam. An analyzing magnet followed by a third counter, displaced by 30°, in triple coincidence measured the relative fraction of negative particles of a particular momentum range. By varying the magnet current, the relative momentum spectrum of the negative particles issuing from the target was determined. The percentage of pions at each momentum was determined by range curve analysis of the beam as previously described.[1] The relative momentum spectrum deduced for negative pions in the laboratory system at 32° will be shown and discussed. The momentum resolution was approximately constant and about 10 percent total width for all points.

* This research was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Luke C. L. Yuan and S. J. Lindenbaum, Phys. Rev. (to be published).

F5. Total Interaction Cross Section of Hydrogen for Positive and Negative 200–700 Mev Pions.* LUKE C. L. YUAN AND S. J. LINDENBAUM, *Brookhaven National Laboratory.*—Measurements of the total interaction cross section of hydrogen for positive and negative pions of several energies have been made. A direct meson beam from the Brookhaven Cosmotron was incident upon a fast triple coincident scintillation counter telescope containing an analyzing magnet arranged to select either negative or positive particles of the required momentum. A large liquid scintillation counter was placed behind the third counter in quadruple coincidence with the monitor telescope. Good geometry attenuation measurements were made for both polyethylene and carbon absorbers placed between the third and fourth counters. Some of the total interaction cross sections of hydrogen deduced from the difference are sum-

TABLE I.

Mean energy	$\sigma\pi^+$ in mb	$\sigma\pi^-$ in mb
265 Mev		56 ± 16
340 Mev	48 ± 9	21 ± 11
450 Mev	28 ± 6	25 ± 3

marized in Table I. These results demonstrate that both the positive and negative pion cross sections drop rapidly from the values obtained by Anderson, Fermi *et al.* and others in the region of 135 to 200 Mev, thus enhancing the possibility of a resonance or near resonance interaction.

* This research was performed under the auspices of the U. S. Atomic Energy Commission.

F6. Total Interaction Cross Section of Negative Pions at Kinetic Energies of 1.0 and 1.45 Bev.* R. L. COOL, L. MADANSKY, AND O. PICCIONI, *Brookhaven National Laboratory.*—The mesons were produced by the 2.3-Bev proton beam of the Cosmotron and emerged after being deflected by the Cosmotron magnet. Attenuation differences CH_2-C and D_2O-H_2O have been measured in "good geometry" with counter telescope and external analyzing magnet. The results are: $\sigma(\pi^-, P) = 49\pm4$ mb at 1.0 Bev; $=34\pm3.5$ at 1.45 Bev and $\sigma(\pi^-, D_2O) - \sigma(\pi^-, H_2O) = 21\pm3$ at 1.0 Bev; $=29\pm3$ at 1.45 Bev. It appears reasonable to assume that at these energies ($\lambda\sim2\times10^{-14}$ cm) the total cross section of deuterium is close to the sum of $\sigma(\pi^-, P)$ and $\sigma(\pi^-, N)$, at least when these two are not larger than $1/2\pi(\hbar/\mu c)^2$. Thus the difference $\sigma(\pi^-, D_2O) - \sigma(\pi^-, H_2O)$ gives $\sigma(\pi^-, N)$. Then, by the currently accepted principle of charge symmetry, $\sigma(\pi^-, N) = \sigma(\pi^+, P)$. Results thus indicate $\sigma(\pi^-, P)$ twice as large as $\sigma(\pi^+, P)$ at 1 Bev which fact has to be contrasted with the low-energy situation where $\sigma(\pi^-, P)$ is as little as about 1/3 of $\sigma(\pi^+, P)$. Comparing our data with those of Lindenbaum and Yuan $\sigma(\pi^-, P) = 25\pm3$ at 0.45 Bev, $\sigma(\pi^+, P) = 48\pm9$ at 0.34 Bev, it appears that $\sigma(\pi^-, P)$ has a second maximum in the 1-Bev region, while $\sigma(\pi^+, P)$ has a minimum in the same region. The data of Shapiro, Leavitt, Chen $\sigma(\pi^-, P) = 47\pm5$ at 0.84 Bev, $\sigma(\pi^-, P) = 27\pm5$ at 0.47 Bev add strength to the conclusion about the high-energy maximum of $\sigma(\pi^-, P)$.

* Under contract with the U. S. Atomic Energy Commission.

F7. Signs of the Phase Shifts in Pion-Proton Scattering.* JAY OREAR, *University of Chicago.*—Ilford G.5 plates were exposed to the 122-Mev external π^+ beam of the Chicago cyclotron. Scatterings with hydrogen in the emulsion were located by area scanning for the recoil protons.[1] Care was taken to observe all single protons down to 10μ in length. This corresponds to a scattering of 12° in the baricentric system. A scanning efficiency greater than 80 percent for these small angle scatterings was established by duplicate scanning. Depending on the signs of the phase shifts, Coulomb interference should give either a large decrease or increase in $d\sigma/d\omega$ in the region of 12° to 19°. Assuming the phase shifts recently determined,[2] positive sign for α_{33} predicts one event while negative sign predicts four events in this region. Of 93 scatterings obtained so far, only one was in this region. These results give 5 to 1 odds on a destructive interference or attractive $P_{\frac{3}{2}}$ force. Scanning will continue until the odds become convincing. Fortunately this is a case where doubling the data more than doubles the odds.

* Supported by the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Jay Orear, Phys. Rev. **91**, 156 (1953).
[2] Anderson, Fermi, Martin, and Nagle, Phys. Rev. **91**, 155 (1953).

F8. Scattering of 65-Mev Pions in Hydrogen. D. BODANSKY, A. M. SACHS, AND J. STEINBERGER, *Columbia University.*—A measurement has been made of the angular distribution of $\pi^-+P\rightarrow\pi^-+P$ and $\pi^-+P\rightarrow\pi^0+N$, using a liquid hydrogen target and scintillation detectors. In the charge exchange scattering one γ ray was detected.

θ_{CM}	$d\sigma/d\Omega(\pi^-\rightarrow\pi^-)$, mb	θ_{CM}	$d\sigma/d\Omega(\pi^-\rightarrow\gamma)$, mb
42	0.91 ± 0.13	50	1.09 ± 0.14
53	0.51 ± 0.08	97	2.13 ± 0.23
70	0.29 ± 0.06	150	3.24 ± 0.37
101	0.23 ± 0.06		
151	-0.01 ± 0.11		

The π^0 angular distribution $d\sigma/d\Omega(\pi^-\rightarrow\pi^0) = \{0.96\pm0.03 - (1.38\pm0.09)\cos\theta + (0.14\pm0.23)[(3\cos^2\theta-1)/2]\}(1.0\pm0.1)$. The experiment, together with previous results on π^+ scattering, offers the possibility of determining the signs of the phase shifts on the basis of the Coulomb interference. The best fit is obtained with $\delta_0^3 = -6.3^0$, $\delta_1^3 = -2.0^0$, $\delta_2^3 = +9.1^0$, $\delta_0^1 = +10.4^0$, $\delta_1^1 = +0.3^0$, $\delta_2^1 = -2.1^0$, corresponding to attractive $P_{\frac{1}{2}}$ interaction. A possible, but poorer, fit with different signs is $\delta_0^3 = +14.5^0$, $\delta_1^3 = -1.4^0$, $\delta_2^3 = -2.8^0$, $\delta_0^1 = -3.7^0$, $\delta_1^1 = -1.6^0$, and $\delta_2^1 = +6.8^0$. The latter, however, is inconsistent with a reasonable extrapolation of the phase shifts reported by the Chicago group at higher energies.

F9. A Measurement of the Fraction of $n+p\rightarrow\pi^0$ Events in which a Deuteron is Formed.* ROGER H. HILDEBRAND, *University of Chicago.*—The branching ratio between the processes $n+p\rightarrow\pi^0+d$ and $n+p\rightarrow\pi^0+n+p$ is of interest since it involves the competition between states of isotopic spin 0 and 1. A measurement of this ratio for 400-Mev neutrons has been performed by measuring the range of the charged particles in coincidence with the two π^0 decay gamma rays. The experimental arrangement was similar to that used for determining the π^0 angular distribution.[1] The conditions were such that the deuteron range was twice the proton range. The results of this measurement indicate that a deuteron is formed in 100 percent of all the π^0 production events. The standard deviation of this figure based on counting statistics is 15 percent.

* Research supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Roger H. Hildebrand, Phys. Rev. **89**, 1090 (1953).

F10. Scattering of Negative Pions by Deuterium.* D. E. NAGLE, *University of Chicago.*—The scattering of 123-Mev negative pions by liquid deuterium has been studied, using scintillation counter telescopes, and 123-Mev pions from the Chicago synchrocyclotron. The differential cross sections for the scattering without charge exchange of negative pions are, in the laboratory system, $6.63\pm0.60\times10^{-27}$ cm²/sterad, $5.05\pm0.40\times10^{-27}$ cm²/sterad, and $(7.33\pm0.50)10^{-27}$ cm²/sterad at angles of 45°, 90°, and 135°. The differential cross sections for the production of photons by 123-Mev negative pions incident on deuterium are 2.39 ± 0.3, 2.30 ± 0.2, and 3.14 ± 0.4 in the same units and at the same angles. A comparison with the cross sections to be expected from a model which assumes incoherent scattering from the neutron and proton in deuterium, using the data from hydrogen scattering[1] and the assumption of charge independence, shows only qualitative agreement.

* Research supported by a joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Anderson, Fermi, Martin, and Nagle, Phys. Rev. **91**, 155 (1953).

F11. Photo Production of Low-Energy Charged π Mesons.* J. R. VOSS, T. R. PALFREY, AND R. O. HAXBY, *Purdue University.*—Following the method of White,[1] the Purdue 300-Mev synchrotron has been used to expose some Ilford 600-micron G-5 plates. A thin Carbon target was placed in the γ-ray beam and reaction products at 90° from the beam were captured in the emulsion. At this time 31 mesons have been identified in the energy range 0–10 Mev, $15\pi^+$, and $15\pi^-$,

and one uncertain. The corrected π^-/π^+ ratio is then 1.4 ± 0.5. A calculation of the cross section for photomeson production in tbis energy range is 0.4 of the value found here at 30 Mev in similar geometry with nuclear emulsions. However, the tentative absolute cross sections obtained are somewhat smaller than values found by other observers. Preliminary exposures with Cu, Sn, and Pb targets have been made with the aim of extending the low-energy measurements to the higher Z materials.

* Work supported in part by contract with U. S. Atomic Energy Commission.

[1] R. H. White, University of California Radiation Laboratory Report, 1319, (1951).

F12. Interactions of 500-Mev Negative Pions with Emulsion Nuclei.* M. CAULTON, M. BLAU, AND J. E. SMITH, *Brookhaven National Laboratory.*—Four-hundred micron Ilford G-5 emulsions have been exposed to the 500-Mev negative meson beam of the Brookhaven Cosmotron. In 600 identified meson induced stars, the nature and energy of the particles causing the outgoing tracks have been determined (grain density, scattering, range), whenever the track length and ionization made this meaningful. For about 30 percent of the light tracks this procedure was possible. On the basis of these measurements in 38 ± 3 percent of the interactions at least one meson has been observed to leave the nucleus. Most of the mesons have suffered great energy losses; however there is no observed relation between angle of emission and meson energy. The angular distribution of the emitted mesons in the laboratory system yields approximately equal backward and forward integrated scattering cross sections. An estimate of charge exchange is obtained by comparing star energies and prong distributions in events with and without emitted charged mesons. Accordingly charge exchange may have occurred in 15 to 20 percent of all interactions. Seven cases of meson production have been identified. The characteristics of the stars and the emitted mesons will be discussed.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.

FRIDAY AFTERNOON AT 2:00

Kent 106

(G. E. PAKE presiding)

Magnetic Resonance, Electronic and Nuclear; Quadrupole Resonance

G1. Hyperfine Structure in the Paramagnetic Resonance of X-Rayed LiF. E. E. SCHNEIDER, *Duke University.**—Single crystals of LiF, irradiated by 180-kv x-rays, have been investigated at 9450 Mc in the sensitive microwave resonance apparatus in Newcastle. Spectrophotometric measurements showed the crystals to have a normal F band at 2480A with color center concentrations ranging from 5 to 15×10^{16} cm^{-3}. The paramagnetic resonance spectrum has a complex structure: There is an intense central peak of about 90 gauss width with a g factor larger than the free-electron value ($g/g_u=1.009$). Superimposed on this is a pattern of 19 weaker and narrower lines which are of equal intensity and are equally spaced at about 60-gauss interval. It is suggested that the broad peak is due to V centers while the 19-line pattern is ascribed to F centers and is interpreted as a resolved hyperfine structure due to interaction with Li nuclei in contrast with the unresolved hfs effect which accounts for the width of F-center resonances in other alkali halides.[1,2]

* On leave from King's College, University of Durham, Newcastle upon Tyne, England.

[1] A. H. Kahn and C. Kittel, Phys. Rev. **89**, 315 (1953).

[2] Kip, Kittel, Levy, and Portis, Phys. Rev. **91**, 1066 (1953).

G2. Paramagnetic Resonance Absorption of Mn^{++} in Single Crystals of $CaCO_3$.* F. KENNETH HURD, MENDEL SACHS, AND W. D. HERSHBERGER, *University of California at Los Angeles.*—A study has been made of the magnetic behavior of single crystals of $CaCO_3$ diluted with 0.06 wt percent of Mn^{++} by means of the paramagnetic resonance absorption spectrum at 9300 mc. The Mn^{++} spectrum consists of 30 well-resolved lines, approximately 3.5 gauss wide, and extending over a range of 1100 gauss. The fine structure splitting is explained in terms of an axial crystalline field, wherein the spectroscopic splitting factors $g_{\parallel}$ and $g_{\perp}$ are introduced, and the crystalline field coefficients D' and d' are introduced. The hyperfine structure is explained in terms of the interaction between electronic and nuclear magnetic moments, wherein the factors A' and B' are introduced. The values obtained for the parameters are:

$g_{\parallel}=2.0022$ $\quad D'=37.5\times10^{-4}$ cm^{-1} $\quad A'=87.82\times10^{-4}$ cm^{-1}
$g_{\perp}=2.0014$ $\quad d'=0.04\times10^{-4}$ cm^{-1} $\quad B'=87.74\times10^{-4}$ cm^{-1}.

* Work supported in part by the U. S. Office of Naval Research.

G3. Magnetic Resonance in Some Cr^{+3} Complexes. L. S. SINGER, *Naval Research Laboratory.*—The magnetic resonance spectra of several trichelate complexes of Cr^{+3} (the oxalate, acetylacetonate, and ethylene diamine) have been measured at a wavelength of 1.2 cm. In these compounds, the zero-field splitting of the ground-state spin quartet, which is much larger than that observed in the chrome alums, gives rise to a rather complicated fine structure. Detailed measurements of the fine structure of the tri-acetylacetonate complex have been carried out on single crystals of both the pure substance and solid solutions containing the isomorphous Al compound. A comparison of the experimental results with a crystalline field theory will be presented. The information concerning molecular structure and chemical bond type which can be inferred from this comparison will also be discussed.

G4. Effects of Imperfections and of Electron Interactions on Magnetic Resonance in Alkali Metals. D. F. HOLCOMB AND R. E. NORBERG, *University of Illinois.*—Nuclear spin lattice relaxation times (T_1) and spin phase memory times (T_2) have been measured between -65°C and 270°C for metallic Na^{23} and Li^7. Spin echo measurements in both metals yield T_2 data which extend to higher temperatures, the diffusion-induced line narrowings previously reported. Coefficients and activation energies for self-diffusion are determined. Above room temperature the T_2 data show lifetime broadening arising from an electron-induced T_1. In the vicinity of the melting points and above an additional broadening becomes observable. Upon melting the lines *broaden* by a factor of about two. We attribute this to a quadrupolar interaction with lattice imperfections. Over much of the temperature

range investigated, T_1 for both metals is nearly inversely proportional to temperature. In addition, Li^7 shows a dipolar T_1 minimum whose shape and position agree well with the self-diffusion hypothesis and the coefficients deduced from the T_2 data. In both metals there are discrepancies between $(T_1)_e$, the component of the observed T_1 which appears to be determined by the conduction electrons, and the predictions of theory. Observed effects which may arise from interactions among the electrons include: a dependence of $(T_1)_e$ on the applied magnetic field, values of $(T_1)_e$ greater than those predicted by Korringa's theory, and a small deviation of the temperature dependence of $(T_1)_e$ from $1/T$.

G5. Nuclear Quadrupole Resonance of Hg^{201}.* H. G. DEHMELT, H. G. ROBINSON, AND WALTER GORDY, *Duke University*.—Five nuclear quadrupole resonance lines have been observed in polycrystalline $HgCl_2$, one due to the mercury isotope Hg^{201} at 354 207±60 kc/sec and four due to the chloring isotopes $Cl^{35,37}$ at 22 230.3±0.8, 22 050.5±0.7, 17 519.7±0.9, and 17 378.9±1 kc/sec. From these frequencies the quadrupole coupling constants $eQq_{zz}h^{-1}(Hg^{201}) = 720$ Mc/sec and $eQq_{zz}h^{-1}(Cl^{35}) = 44.3$ Mc/sec are evaluated. A quadrupole coupling constant per p electron in the $6s6p$ configuration of free Hg, $eQq_{zz}h^{-1}(Hg^{201}, p_z) = 950$ Mc/sec, is deduced from the Hg^{201} coupling in $HgCl_2$. This value can be directly compared with the coupling of the $6s6p\ ^2P_2$ HgI term, $eQq_{zz}h^{-1} \times (Hg^{201}, p_z) = 780$ Mc/sec, which is equivalent to the value of the quadrupole parameter $B = 0.27 \times 10^{-3}$ cm^{-1} known from optical hfs investigations.[1] However, while a standard analysis of the hfs of the $^2P_2$ term gives $Q(Hg^{201}) = 0.5 \times 10^{-24}$ cm^2,[1] a discrepant value $Q(Hg^{201}) = 0.2 \times 10^{-24}$ cm^2 [2] is obtained from the $^1P_1$ term. Our result favors the larger value found for the $^2P_2$ term. An investigation of the Zeeman-Effect of the Hg^{201} nuclear quadrupole resonance line is in progress.

* Supported by the U. S. Office of Ordnance Research.
[1] Schuler and Schmidt, Z. Physik **89**, 239 (1936).
[2] Murakawa and Suwa, J. Phys. Soc. Japan **5**, 429 (1950).

G6. The Effect of Molecular Motion on the Intensity of Pure Quadrupole Resonances.* MYER BLOOM, H. S. GUTOWSKY, D. W. MCCALL, AND J. G. POWLES, *University of Illinois*.—The Cl^{35} pure quadrupole resonance has been observed as a function of temperature in a number of molecular solids. In some cases the absorption changes more rapidly with temperature than predicted by the Boltzmann factor and the resonance disappears at temperatures considerably below the melting point. The anomalous attenuation extends over temperature ranges of 10° to 40° in the compounds studied thus far and is accompanied by relatively small increases in line width. A theoretical analysis, which accounts for the available data, is based on a model in which there are low-frequency, thermally activated, "sudden" reorientations of molecular groups, such as CCl_3. The following explicit equation has been derived for f, the fractional decrease in the surplus population of the lower state compared to the Boltzmann value:

$$f = 1 - \frac{T_1}{\tau} \ln\left(\frac{\tau + T_1}{T_1}\right) \frac{1 - (1 - \frac{3}{2}\sin^2\theta)}{1 - (1 - \frac{3}{2}\sin^2\theta)[T_1/(\tau + T_1)]}$$

τ is the average time between jumps, which are assumed to be random; the field gradient is taken to have axial symmetry around the Cl-M bond, and θ is its reorientation angle.

* Assisted in part by the U. S. Office of Naval Research and a Grant-in-Aid from E. I. Du Pont de Nemours Company, Inc.

Invited Paper

G7. Polarization of Nuclear Spins in Metals by the Overhauser Method. C. P. SLICHTER, *University of Illinois*. (30 min.)

FRIDAY AFTERNOON AT 2:00

Eckhart 133

(N. S. GINGRICH presiding)

Apparatus of Nuclear Physics

H1. Loading of Nuclear Emulsions with Lithium Gloss Specks.* J. H. ROBERTS, J. HAUGSNES, AND D. E. WOOD, *Northwestern University*.—In order not to rely primarily upon triton-alpha discrimination to identify the point of disintegration in tracks resulting from $Li^6(n, \alpha)H^3$ in nuclear emulsions, the lithium has been incorporated into the emulsion in the form of a single layer of specks of lithium glass at the center of the emulsion. The lithium glass, containing 30 percent Li_2O, prepared by H. P. Hood of the Corning Glass Works, is ground in a ball mill into specks having diameters of the order of three microns. The specks, suspended in absolute alcohol, are sprayed on a 50-micron layer of Eastman NTA, Ilford C2 or E1 emulsion to a density of about 50 micrograms of glass/cm^2. As soon as the alcohol has dried another 50-micron layer of emulsion is added. The glass can be made in sufficiently small quantities to use lithium highly enriched in Li^6. Measurements of a few hundred tracks in plates exposed to 260-kev neutrons indicate that a resolution of ±75 kev is possible at this energy under conditions of isotropic neutron incidence. The specks are clearly visible with a microscope suitable for measuring the tracks.

* Work supported by U. S. Atomic Energy Commission contract.

H2. Kinetics of the Circulating-Fuel Nuclear Reactor. WILLIAM KRASNY ERGEN, *Oak Ridge National Laboratory*.—In nuclear reactors power oscillations are usually damped because of the influence of delayed neutrons. In a circulating fuel reactor, such as the Oak Ridge Homogeneous Reactor, a part of the delayed neutrons are given off outside the reactor and their damping influence is thus lost. However, if the reactor has a negative temperature coefficient of reactivity, the circulation of the fuel introduces some damping of power oscillations, independently of delayed-neutrons. At least this is true if there is no interaction between the power oscillations on one hand and mechanical oscillations of the reactor or the flow pattern of the fuel on the other. The damping by fuel circulation can be maximized by proper choice of design parameters, but it vanishes in limiting cases. A simple discussion of the foregoing for the nonlinearized case will be presented.

H3. Scintillation Detector for the Brookhaven Fast Chopper. H. PALEVSKY, H. R. MUETHER, AND A. STOLOVY, *Brookhaven National Laboratory*.*—We have been investigating the properties of a fused mixture of ZnS-Ag and B_2O_3 for a neutron

detector to be used with the Brookhaven fast chopper for energies from 10 ev to 10 kev. The detector is required to have fast response ($\sim 0.2\mu$sec) and low γ sensitivity. ZnS-Ag seems to be the best suited to these requirements. The decay of the phosphor under α bombardment has been investigated from 0.02 to 25μsec. The decay can be fitted to a power law of the form $ct^{-\alpha}$, where $\alpha = 1.36$, so that in 0.2μsec the integrated voltage signal rises to 25 percent of the signal level at 10μsec. The low gamma sensitivity is attributed to the high density of traps relative to the density of secondary electrons formed from the Compton processes.† The problem of getting maximum neutron efficiency is twofold. First, the penetration of the α particles from the $B^{10}(n, \alpha)$ reaction into the ZnS, and second, the generation and transmission of the light through the ZnS. An investigation has been made of these factors as a function of ZnS grain size, and varying proportions of ZnS and B_2O_3. The results will be presented at the meeting.

* Work carried out under contract with the U. S. Atomic Energy Commission.
† H. Kallman (private communication).

H4. A Method of Eliminating Cathode Activation Effects in the G-M Counter.* H. R. CRANE, *University of Michigan.*—Activation of the cathode by positive ions, resulting in immediate or delayed emission of thermal-energy electrons,[1,2] accounts for much of the capricious behavior in Geiger counters, especially when gases other than the "standard" ones are used. A counter and circuit have been devised in which this effect is eliminated. A grid is interposed between anode wire and cathode cylinder. While waiting for a discharge, the grid is negative with respect to the cylinder, so that electrons originating at the cylinder due to activation are prevented from reaching the anode. When a discharge occurs, the grid is made positive with respect to the cylinder, and held so until ion collection is complete. This (a) lowers the field around the anode, quenching the discharge, and (b) causes the positive ions to be collected on the cylinder and not on the grid. Thus, the grid, which is the only electrode which can emit electrons which will cause counts, is not subject to activation by positive ions. Behavior of this counter with a number of gases will be reported.

* Supported by the Michigan Memorial-Phoenix Project.
[1] H. R. Crane, Phys. Rev. **75**, 985 (1949).
[2] M. L. Wiedenbeck and H. R. Crane, Phys. Rev. **75**, 1268 (1949).

H5. An Ion Source for Doubly Charged Helium. C. E. BRADFORD, T. KIKUCHI, AND W. E. BENNETT, *Illinois Institute of Technology.*—A Zinn type ion source used on an an electrostatic generator has been modified in several ways. The probe canal was replaced by an exit aperture and focusing lenses, increasing the usable output of singly charged helium ions by a factor of seven, to thirty microamperes. The "nose" was eliminated to make the arc self-starting, and a circular filament of smaller diameter was used. It was then possible to operate the ion source at smaller gas pressures than had previously been used. With the gas flow one-fourth of that required to start an "arc," the ion source still gave ten microamperes of helium. The beam of doubly charged helium was then one-half percent of the total. This is near the theoretical maximum for 300-volt electrons. Magnetic analysis was used to separate the doubly charged helium and molecular hydrogen beams. The latter beam would affect the usability of the helium beam if it struck the target since it varied during the day as the ion source was outgassed.

Post-Deadline Papers, If Any

FRIDAY AFTERNOON AT 2:00

Oriental Institute

(CYRIL S. SMITH presiding)

Whiskers and Solid-State Physics

I1. Mercury Whiskers. G. W. SEARS, *General Electric Research Laboratory* (introduced by D. Turnbull).—It has been found that whiskers of solid mercury about 1 mm long and 0.01μ in radius can be grown on a cold glass surface by vapor condensation. The whiskers grow 5000 times faster than can be accounted for by an impingement rate of mercury atoms on the advancing end from the vapor. The new whiskers are in Brownian motion. When a whisker grows to about 1 mm long it ceases preferential growth and grows isotropically. The whisker first ceases Brownian motion and later shows cyclic appearance of interference colors. The supersaturation ratio necessary to nucleate an atomic layer of mercury on a low-index plane is 4×10^8. The whiskers appear at supersaturation ratios 10 000-fold less than this figure. The whiskers are deduced to form on crystallites of devitrified glass which present the end of a screw dislocation. The whisker can only grow along the screw axis which is transposed into the mercury structure. The faces parallel to the axis are low index and present no growth sites. The rapid growth occurs by impingement on the faces parallel to the axis followed by surface diffusion to the end.

I2. Accelerated Growth of Tin Whiskers. R. M. FISHER, L. S. DARKEN, AND K. G. CARROLL, *United States Steel Corporation.*—It is found possible to accelerate markedly the growth of the tin whiskers, first observed[1] as a spontaneous growth on tin plate. Acceleration, by a factor on one hundred or more, is achieved by application of static pressure (of the order of a ton per square inch) applied by mounting tin plate in a ring-type metallographic clamp. Edgewise cross sections are polished, and the growth of the tin whiskers from the tin layer is observed under a microscope. A sequence of photomicrographs showing the growth of the whiskers will be shown. The whiskers grow at constant rates, as high as 100A/sec, until they nearly reach their maximum length (about 2 mm).

[1] Compton, Mendizza, and Arnold, Corrosion **7**, 327 (1951).

I3. Strain Sensitivity of AuCu and $AuCu_3$ Alloys.* G. C. KUCZYNSKI, *University of Notre Dame.*—Wires of ordered and disordered AuCu and $AuCu_3$ alloys were stretched elastically, their electrical resistance measured and the strain coefficient of electrical resistance $(dR/Rd\epsilon)_{\epsilon=0}$ determined, where R is electrical resistance and ϵ strain. It has been found that: (1) The AuCu wires ordered at 390°C increased steadily their resistance with strain. $(dR/Rd\epsilon)_{\epsilon=0}$ ranged from +1.0 to +2.0. (2) The AuCu wires ordered at 350°C decreased markedly their electrical resistance. $(dR/Rd\epsilon)_{\epsilon=0}$ ranged from −20 to −100. After a certain strain was exceeded the increment of resistance was observed. (3) Similar behavior was observed in the case of $AuCu_3$ wires ordered at 370°C $(dR/Rd\epsilon)_{\epsilon=0}$ ranged from −4 to −10. (4) The fully disordered alloys exhibited small positive coefficients of strain sensitivity of the order of +1.2 for AuCu and +1.5 for $AuCu_3$ alloy.

* Supported by Baldwin-Lima-Hamilton Corporation.

I4. Internal Friction of Alloys of Gold and Nickel. C. ANG AND C. WERT, *University of Illinois.*—The internal friction behavior of some Au-Ni alloys has been determined in the temperature range 20°C to 700°C. Two peaks are seen for all alloys; one of these is the grain boundary peak at about 400°C and the other the "pair-relaxation" peak of Zener at somewhat lower temperatures. The presence or absence of the second peak depends markedly on the heat treatment prior to measurement. To observe it, one must quench the alloy from the solid solution region above the phase separation line. The height and position in temperature of the peak depends somewhat on the quench temperature in this solid solution region. The peak disappears upon isothermal annealing at temperatures areound 300°C. This disappearance is thought to be associated with the occurrence of phase separation in the quenched alloys. The data obtained by this method show that some processes are taking place upon annealing much earlier than would be deduced from measurements of changes of electrical resistance or mechanical properties. The activation energy for the relaxation process is about the same as that for diffusion in the alloys. The data obtained can thus far be given only tentative explanations.

I5. Internal Friction of Dilute Alloys of Lead. J. WEERTMAN AND E. I. SALKOVITZ, *Naval Research Laboratory.*—The internal friction of single crystals of binary alloys of lead containing 0.01 to 1 (nominal) atomic percent of Bi, Cd, and Sn was measured as a function of temperature and strain amplitude. Measurements were made from room temperature to 300°C using the Marx technique[1] and operating at 30 kc. The decrement increased with increasing temperature. At low strains the decrement was independent of the amplitude of vibration. As the strain amplitude was increased the decrement started to rise when a "critical" amplitude was reached. This critical amplitude was increased by increasing the alloying content of the material and was decreased by as much as a factor of ten by raising the temperature from room to 300°C. The critical strain amplitude at room temperature decreased from 10^{-6} to 10^{-7} as the alloying content was lowered.

[1] J. Marx, Rev. Sci. Instr. **22**, 503 (1951).

I6. Diffusion of Cadmium, Indium, and Tin in Single Crystals of Silver.* C. T. TOMIZUKA, *University of Illinois.*—In the periodic table, silver is followed by cadmium, indium, tin, and antimony in this order. Since the measurements of self-diffusion in silver[1] and of diffusion of antimony in silver,[2] a study has been continued to determine the activation energy and frequency factor for the diffusion of other neighboring elements in silver single crystals of 99.99 percent purity. Using Cd^{115}, In^{114}, and Sn^{113} as tracers, satisfactory results were obtained with a thin-wall immersion beta-counter for counting a cylindrical layer of solution. Diffusion of cadmium in silver yields $D=0.2\exp(-40\,500/RT)$ and of indium in silver gives $D=0.2(-39\,700/RT)$. These as well as the expression for tin are compared with the data of Seith and Peretti[3] and with the expression for self-diffusion and diffusion of antimony in silver.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Slifkin, Lazarus, and Tomizuka, J. Appl. Phys. **23**, 1032 (1952).
[2] Sonder, Slifkin, and Lazarus, Phys. Rev. **91**, 245 (1953).
[3] W. Seith and E. Peretti, Z. Elektrochem. **42**, 570 (1936).

I7. Reflectivity of Silver in the Near Infrared.* L. G. SCHULZ, *University of Chicago.*—The reflectivity of a glass-silver interface was measured in the wavelength range of 1 to 3 microns. Each of the samples used was prepared by depositing silver from the vapor on part of the hypotenuse face of a right-angled glass prism. The intensity of the light reflected internally at the glass-metal interface was compared with that which was totally reflected at the glass-air interface. The ratio of values for the s and p planes agreed with that predicted by electromagnetic theory. Using reflectivities obtained by this method together with previously determined values of the absorption coefficient, the index of refraction n was calculated. With this value of n the calculated reflectivity at an air-silver interface was found to be 0.993 as compared with 0.996 given by the free-electron theory of metals. The difference of 0.003 between experimental and calculated values, which was found also for silver-gold alloys, could be an experimental error or it might indicate an anomalous optical surface behavior. It will be shown that the well-known work of Hagen and Rubens is incorrect both experimentally and theoretically.

* Supported in part by the U. S. Air Force.

I8. The Electrical Resistivity of Pure Tellurium at the Melting Point and in the Liquid State.* A. EPSTEIN AND H. FRITZSCHE, *Purdue University.*—The electrical resistivity of doubly distilled, spectroscopically pure tellurium undergoes a discontinuous change at the melting point. Near the melting point its value in the liquid is 0.00055 ohm-cm and in the solid between 0.006 ohm-cm and 0.012 ohm-cm depending on the crystal orientations of the solidified material. In the liquid the resistivity continues to decrease with increasing temperature to a value of about 0.0004 ohm-cm at 550°C. At higher temperatures the resistivity curve flattens out, and resistivity finally increases above 625°C. The resistivity-temperature curve can be followed reproducibly by heating and cooling in the liquid state as well as in the solid, if one ascertains that the solidified material has the same orientation.

* Work supported by U. S. Army Signal Corps.

I9. The Variation of Magnetoresistivity and Resistivity of AuCu during Annealing from the Cold-Worked and Thermally-Disordered States. B. WIENER AND G. GROETZINGER, *Lewis Flight Propulsion Laboratory.*—In order to study the changes occurring in the states of AuCu during the processes of thermal disordering, of cold working, and of annealing from the disordered condition, measurements were made of the resistivity and magnetoresistivity of samples of AuCu which had been thermally disordered and were then annealed at 150°C and 265°C; of samples completely disordered by cold work and then annealed at 265°C; and of initially ordered samples when subjected to varying amounts of cold work. It was found that AuCu has a coefficient of magnetoresistivity of 1.8×10^{-12} $gauss^{-2}$ in the ordered state and of 6×10^{-14} $gauss^{-2}$ in the disordered state regardless of the method of disordering. Furthermore, the curves of magnetoresistivity against resistivity obtained for the thermally disordered samples annealed at the two different temperatures are different from each other; and both differ from the curve obtained for the samples completely disordered by cold work and then annealed. The last curve, however, cannot be distinguished from that found

for the samples subjected to varying amounts of cold work. It follows that thermally disordered samples pass through different sequences of states when annealed at different temperatures; and that, in general, samples initially disordered by cold work do not go through the same set of states when ordered by annealing as do samples disordered by quenching.

I10. Diffuse Magnetic Scattering of Neutrons: Zinc Ferrite.* B. N. BROCKHOUSE,† L. M. CORLISS, AND J. M. HASTINGS, *Brookhaven National Laboratory.*—Diffuse scattering of neutrons of wavelength 1.06A has been studied with apparatus which permits work close to the forward direction under conditions of low and flat background. Corrections for multiple scattering (in flat specimens) were made by using calculations of Chandrasekhar and of Vineyard. This procedure was tested by extensive measurements on beryllium, lead, bismuth, and thorium, in which multiple scattering is the only important diffuse scattering. For zinc ferrite, the scattering at room temperature can be extrapolated to the theoretical value in the forward direction, At larger angles, separation of magnetic and thermal diffuse scattering involves difficulties. The Debye-Waller factor and measurements of diffuse scattering as a function of the temperature, have been used in attempts to separate the two. A form factor will be presented and discussed. The diffuse scattering at liquid nitrogen temperatures shows anomalies, including some excess small angle scattering. This behavior, still under investigation, suggests short-range magnetic coupling between ions. Long-range magnetic order, as indicated by the presence of diffraction peaks, becomes noticeable only in the neighborhood of helium temperatures.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.
† Guest scientist, on leave from Atomic Energy of Canada, Ltd., Chalk River, Canada.

I11. Neutron Diffraction in Vitreous Silica.* R. J. BREEN† AND A. H. WEBER, *Saint Louis University and Argonne National Laboratory.*—The theory of liquid structure determinations by x-rays[1] has been extended to neutron scattering in vitreous silica. A method of analysis[2] using total neutron scattering cross sections from transmission experiments is developed and the results are compared to those from differential scattering. The radial density distribution of atoms is obtained and results are compared with Warren's values from x-ray diffraction.[3]

* This work was supported in part by the Owens-Illinois Glass Company and the U. S. Army Office of Ordnance Research.
† Now at Mound Laboratory, Miamisburg, Ohio.
[1] N. S. Gingrich, Revs. Modern Phys. **15**, 90 (1943).
[2] Suggested by M. Hamermesh.
[3] B. E. Warren, J. Am. Ceram. Soc. **17**, 249 (1934); B. E. Warren and A. D. Loring, J. Am. Ceram. Soc. **18**, 269 (1935).

I12. The Thermal Conductivity of Sodium Chloride.* WILLIAM H. BESSEY AND HAROLD WEISBROD, *Missouri School of Mines and Metallurgy.*—An apparatus has been essentially completed for measuring the thermal conductivity of ionic crystals as a function of temperature from a little above room temperature nearly up to the melting point. It is a modification of the steady-state guard-ring type of apparatus, and consists of a heater sandwiched between two identical cylindrical samples and placed between independent large copper receivers which are kept at the same temperature. The whole arrangement is placed in a vacuum to cut down convection losses and sample corrosion. Synthetic optical windows of sodium chloride were used for the initial testing of the equipment. Preliminary results for the conductivity at 100°C are in reasonable agreement with the values given by Ballard *et al.*[1]

* Supported by a grant from the Research Corporation.
[1] Ballard, McCarthy, and Davis, Rev. Sci. Instr. **21**, 905 (1950).

FRIDAY EVENING AT 7:00

Hutchinson Commons

(ENRICO FERMI presiding)

Banquet of the American Physical Society

After-dinner speakers: S. K. ALLISON, D. H. LOUGHRIDGE, AND R. S. MULLIKEN.

SATURDAY MORNING AT 9:30

Eckhart 133

(W. H. ZINN presiding)

Reactions of Transmutation; Nuclear Energy Levels

K1. Nuclear Coulomb Excitation by Heavy Particles. DAVID L. HILL, *Los Alamos Scientific Laboratory and Vanderbilt University.*—Recent observations[1] on proton bombardment of tantalum and other materials have confirmed theoretical expectations[2] on the Coulomb excitation of low-lying rotational states of aspherical nuclei. However, the excitation of x-rays complicates the measurement of the relevant gamma rays. The advantages of using heavier particles are simply illustrated by comparing the results expected with beams of, say, 1-Mev protons, 4-Mev alpha particles, and 14-Mev nitrogen ions. The K x-ray production by projectiles of charge z, velocity v, and reduced mass m is roughly proportional to z^2v^4, while the Coulomb excitation of rotational nuclear states goes[2] as m^2v^2g, g being a function which decreases as the collision becomes more nearly adiabatic. That the z/m ratio for protons is twice its value for other projectiles more than doubles the g value pertinent to heavier projectiles. Hence, the cross section for Coulomb excitation increases by factors

of about 37 and 400 in passing, respectively, to bombardment by alpha particles and by nitrogen ions, while the relative x-ray excitation diminishes by a factor of about eight.

[1] T. Huus and Č. Zupančič, Danske Math.-fys. Medd. **28**, No. 1 (1953); C. L. McClelland and C. Goodman, Phys. Rev. **91**, 760 (1953).
[2] K. A. Ter-Martirosyan, J. Exptl. and Theoret. Phys. (U.S.S.R.) **22**, 284 (1952); A. Bohr, and B. R. Mottelson, Danske Math.-fys. Medd. **28**, No. 16 (1953).

K2. Nuclear Interactions of High-Energy Nucleons. H. McMANUS, W. T. SHARP, AND H. GELLMAN, *Chalk River Laboratories.*—Cascade nucleon yields and residual excitation energies have been calculated by a Monte Carlo method[1] with the Toronto Ferranti computer for aluminum, silver-bromine, and uranium, bombarded by 90- to 700-Mev nucleons. The observed differential free nucleon-nucleon cross sections (extrapolated to 700 Mev) are used, and neutrons and protons are distinguished throughout. Averages per inelastic event for silver-bromine are summarized in Table I.

TABLE I.

E Mev	Nucleon in	Excitation energy Mev	No. of prompt neutrons	No. of prompt protons
90	n	42	1.1	0.4
90	p		1.0	0.6
400	n	52	2.0	0.8
400	p		1.4	1.9
700	n	50	2.8	1.5
700	p		1.3	2.2

The residual excitation energy at 400 Mev is 35 Mev for aluminum and 94 Mev for uranium. For 400-Mev incoming neutrons, the neutron-proton ratio is 1.7 for aluminum and 2.4 for uranium.

[1] Bernardini, Booth, and Lindenbaum, Phys. Rev. **88**, 1017 (1952).

K3. Yields near Threshold for (p, n) Reactions in Intermediate Nuclei. C. H. JOHNSON AND C. C. TRAIL, *Oak Ridge National Laboratory.*—Relative neutron yields have been observed for neutron energies up to 100 kev above the threshold for the (p, n) reaction in ten intermediate nuclei. Thick targets were bombarded with protons from the Oak Ridge 2.5-Mev Van de Graaff, and neutrons were detected with three BF_3 counters in paraffin surrounding the target. The (p, n) reaction cross sections were thereby determined relative to each other to thirty percent accuracy. The ten cross section curves show an extreme variation of 10^8. The entire set is in good agreement with the cross sections predicted on the basis of the continuum theory of the compound nucleus.[1] Ground-state spins and parities were assigned according to the nuclear shell model. This description requires a single arbitrary constant, namely, the absolute neutron counting efficiency. A preliminary measurement of this efficiency is in rough agreement with the required arbitrary constant. For one of the yield curves, $A^{75}(p, n)Se^{75}$, the nuclear shell model gives two possible Se^{75} ground-state assignments, $p_{\frac{1}{2}}$ or $g_{9/2}$. Of these, $p_{\frac{1}{2}}$ gives better agreement between theory and experiment.

[1] W. Hauser and H. Feshbach, Phys. Rev. **87**, 366 (1952).

K4. Low-Energy Yield of (α, n) Reactions. W. E. BENNETT, P. A. ROYS, AND B. J. TOPPEL, *Illinois Institute of Technology.*—The yield of neutrons from a thin beryllium target bombarded by helium from an electrostatic generator was measured as a function of bombarding energy up to 1.5 Mev. The curve was continued to higher energies using doubly charged helium. The known strong resonance at 1.9 Mev was observed and also resonances at 0.53 and 0.61 Mev, the latter being unusually narrow. Both resonances were observed also in the yield curve of gamma radiation. The angular distribution of neutrons showed marked assymmetry, the yields at zero and at about ninety degrees being large. The high-energy group of neutrons from the reaction is responsible for the maximum at zero degrees and the large energy group for the second maximum. In bombarding boron, five resonances in the yield of neutrons were observed below 1.5 Mev.

K5. Gamma-Radiation from an Excited State of Li^6.* N. M. HINTZ, J. M. BLAIR, AND D. M. VAN PATTER, *University of Minnesota.*—$He^3(d, \gamma)Li^5$ capture gamma radiation has been observed from a chamber containing helium enriched to 95 percent He^3 purified over a charcoal trap, using a NaI scintillation counter and single-channel discriminator. Measured relative to the $Li^7(p, \gamma)$ gamma rays, the extrapolated end point of the pulse distribution corresponded to 16.6 ± 0.2 Mev at $E_d=0.46$ Mev. The observed shift of gamma-ray energy with deuteron energy was consistent with assignment to the $He^3(d, \gamma)Li^5$ reaction. This gamma radiation was not observed when the chamber was filled with He^4 or air. The excitation curve was measured at 90° from $E_d=0.2$ to 2.6 Mev. This curve rises rapidly to a broad maximum at approximately 0.46 Mev, in a manner similar to the $He^3(d, p)He^4$ excitation curve.[1] Above this energy, the yield drops slightly, then rises slowly to the highest energy measured, suggesting the presence of nonresonant capture. The angular distribution was found to be roughly isotropic from 0 to 90°. A preliminary cross section of 2×10^{-28} cm² has been estimated at $E_d=0.46$ Mev, assuming a thick-target yield of 1.9×10^{-8} γ rays/proton for the 441-kev $Li^7(p, \gamma)$ resonance.[2]

* This work has been supported by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Yarnell, Lovberg, and Stratton, Phys. Rev. **90**, 292 (1953).
[2] W. A. Fowler and C. C. Lauritsen, Phys. Rev. **76**, 314 (1949).

K6. Angular Distribution of $Li^6(n, \alpha)H^3$ for Fast Neutrons.* JAMES B. WEDDELL,† AND JAMES H. ROBERTS, *Northwestern University.*—We have previously reported investigation[1] of the angular distribution and cross section of $Li^6(n, \alpha)H^3$ occurring in photographic emulsions containing enriched Li^6. We have determined the yield of tritons per steradian, in the center-of-mass system, for neutron energies 1.1, 1.5, 2.0, and 2.5 Mev. Using spherical harmonics, these yields were fitted to series $Y=A+B\cos\phi_0+C\cos^2\phi_0$, where ϕ_0=neutron-triton angle. Values of A, B, C will be given. The statistical accuracy of the data is not adequate to rule out terms of higher order. We have also measured the capture cross section of Li^6 for 1.5- and 2.0-Mev neutrons, obtaining 0.32 ± 0.06 and 0.27 ± 0.04 barn, respectively. These values agree, within the limits stated, with those reported by Ribe.[2]

* This work was performed under U. S. Atomic Energy Commission contract.
† Now at Westinghouse Research Laboratories, East Pittsburgh, Pennsylvania.
[1] J. B. Weddell and J. H. Roberts, Phys. Rev. **89**, 891 (1953); Darlington, Hangsnes, Mann, and Roberts, Phys. Rev. **90**, 1049 (1953).
[2] F. L. Ribe, Phys. Rev. **87**, 205 (1952); private communication.

K7. $Li^7(d, t)Li^6$ Reaction. R. L. MACKLIN AND H. E. BANTA, *Oak Ridge National Laboratory.*—The cross section for the reaction $Li^7(d, t)Li^6$ has been measured by collecting and measuring the tritium produced by the reaction. The targets are evaporated enriched Li^7F on aluminum disks. About 200 $\mu g/cm^2$ of aluminum was evaporated on top of each target to stop the tritons emerging in the backward hemisphere. The tritium produced was driven out by heating in a hydrogen-argon atmosphere and collected in a proportional counter where the beta disintegrations of the tritium were then counted. Using this method, approximately 11^9 atoms of tritium equals the counter background counting rate. The procedure has been calibrated by two methods: tritium produced by the $Li^6(n, \alpha)t$ reaction is a known neutron flux has been used and also tritium from a Cockcroft-Walton accelerator. Although further work is necessary, on the second method in particular, a final accuracy of ±10 percent for the cross sections does not seem unreasonable. The cross section in-

creases from threshold (1.3 Mev) to the maximum energy obtainable with the 2-Mev Van de Graaff (2.5 Mev) and is approximately 100 millibarns at this maximum energy.

K8. Neutrons from the Proton Bombardment of N^{14}.† F. AJZENBERG. *M.I.T. and Boston University*, W. FRANZEN* AND J. G. LIKELY, *Princeton University*.—A foil of melamine[1] ($N_6C_3H_6$), 200 kev thick, has been bombarded with 17.3-Mev protons from the Princeton cyclotron. The resultant neutrons have been studied by means of Ilford C-2 emulsions, 200 and 400 microns thick, mounted approximately 4.5 inches from the target and at five angles to the incident beam. Preliminary measurements at 30, 60, and 150 degrees (1700 tracks) indicate a ground-state Q value of -6.0 ± 0.2 Mev, giving a mass defect for O^{14} of 12.2 Mev, in good agreement with beta-decay results.[2] The data also indicate levels at excitation energies greater than 5 Mev.

† This work has been supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
* Now at the University of Rochester.
[1] We are indebted to K. G. Standing for this foil.
[2] R. Sherr and G. B. Gerhart, Phys. Rev. **91**, 909 (1953).

K9. Gamma Rays from the Inelastic Scattering of Protons by Neon.* MASON C. COX, JAN J. VAN LOEF, AND D. A. LIND, *University of Wisconsin*.—Observations have been made on the protons resulting from elastic and inelastic scattering of neon.[1,2] We have observed the gamma rays arising from inelastic scattering on Ne^{20} and Ne^{22}, using a 2- ×2-inch cylindrical NaI(Tl) crystal spectrometer with pulse-height analysis. Measurements of the yield of the 1.64-Mev gamma from Ne^{20} and the 1.28-Mev gamma from Ne^{22} were made for bombarding energies between 1.35 and 4.4 Mev. Levels in Na^{21} are found at 1.97-, 2.09-, 2.15-, 2.73-, 3.19-, 3.45-, 3.56-, 3.57-, 3.84-, and 4.00-Mev proton bombarding energy as measured in the laboratory system. No evidence for a level at 2.2 Mev in Ne^{20}, nor for the level at 0.4 Mev in Ne^{22}, was observed, and no other prominent gamma rays were observed.[3] Angular distributions of the 1.64-Mev radiation and the capture cross sections for protons by Ne^{20} as measured by the Na^{21} positron activity were taken at several resonances.

* Work supported by Wisconsin Alumni Research Foundation and the U. S. Atomic Energy Commission.
[1] Haeberli, Galonsky, Goldberg, and Douglas, Phys. Rev. **91**, 438 (1953).
[2] Galonsky, Haeberli, Goldberg, and Douglas, Phys. Rev. **91**, 439 (1953).
[3] F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 321 (1952).

K10. Angular Distribution of α Particles from the $Na^{23}(p,\alpha)Ne^{20}$ Reaction. P. H. STELSON, *Oak Ridge National Laboratory*.—The angular distribution of α particles produced by the $Na^{23}(p,\alpha)Ne^{20}$ reaction and leading to the ground state of the residual Ne^{20} nucleus has been measured at six resonances occurring in the region $Ep=1$ to 2 Mev. The particles were detected with a gas-filled counter fitted with a thin (0.5 air-cm thickness) nickel foil window. By means of pulse-height selection those α particles leaving Ne^{20} in the ground state could be clearly distinguished from those leading to the first excited state. The targets were prepared by evaporation in vacuum of NaI onto thin (25 micrograms/cm²) Formvar backings. The ground state of Ne^{20} is a 0^+ state and this has the consequence that certain types of resonant states are strictly forbidden to decay by this channel. If the ground state of sodium is assigned on even parity, as is indicated by the shell model, the states which can decay by this channel are restricted to the sequence 0^+, 1^-, 2^+, 3^-, etc. The calculated angular distribution for a given type of state is not unique in many cases in that an unknown mixture of the channel spins enters as well as possible admixtures of higher 1 values. The most plausible assignments for the character of the resonances will be given.

K11. Slow Neutron Capture Gamma Rays from Titanium.* HENRY T. MOTZ, *Brookhaven National Laboratory*.—Six gamma rays have been measured from the $Ti(n,\gamma)Ti$ reaction in the energy range of 300 kev to 2000 kev by means of the photoelectric effect in uranium converters. In order to reduce the background, coincidences between the K photoelectrons focused in a thin-lens spectrometer and the K x-rays of the uranium converter are recorded. This technique also eliminates the L photopeaks. $Ti^{48}(n,\gamma)Ti^{49}$ is known to account for 0.95 of the thermal neutron absorption in natural titanium,[1] and, since the intensities of all six lines are >0.05, they originate from this isotope. Preliminary energy values are 0.34, 0.51, 1.385, 1.51, 1.59, and 1.78 Mev. These values agree with the level scheme of Ti^{49} as given by Pieper[2] and Kinsey[3] except for the 510-kev line.

* Research performed at Brookhaven National Laboratory under the auspices of the U. S. Atomic Energy Commission.
[1] H. Pomerance, Phys. Rev. **88**, 412 (1952).
[2] G. Pieper, Phys. Rev. **88**, 1299 (1952).
[3] B. B. Kinsey and G. A. Bartholomew, Phys. Rev. **89**, 375 (1953).

K12. Angular Distribution of Protons from the Reaction $Zn^{68}(d,p)Zn^{69}$. F. S. EBY, R. D. HILL, AND W. K. JENTSCHKE, *University of Illinois*.*—The (d,p) stripping theory of Butler has been employed in the interpretation of the angular distributions of protons from the reaction $Zn^{68}(d,p)Zn^{69}$. Deuterons of 12 Mev were used to bombard a target of isotopically enriched Zn^{68} deposited on a thin gold backing, and a sodium iodide scintillation counter was used to detect protons emitted between angles of 7 and 90 degrees. The theoretical curves which most nearly fit the observed proton distributions are those with $1_n=1$ and $1_n=4$ for the groups associated with the ground state and the 439-kev 13.6-hr isomeric level, respectively. These values of 1_n are consistent with the shell theory assignments[1] of $p_{\frac{1}{2}}$ for the ground state and $g_{9/2}$ for the metastable state of Zn^{69}. The magnitude of the peak associated with the isomeric level is 0.4 times that of the ground level and is significantly greater than is predicted by stripping theory and a one-particle nuclear model. The Q value for the reaction leaving Zn^{69} in the ground state has been determined as 4.16 ± 0.15 Mev.

* Assisted by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).

K13. Proton Induced Reactions in Bismuth. C. G. ANDRE, W. J. RAMLER, E. G. RAUH, R. J. THORN, AND J. R. HUIZENGA, *Argonne National Laboratory*.—The (p,γ), (p,n), and $(p,2n)$ cross sections of bismuth for 6-11 Mev protons were determined by measuring the alpha activities of the polonium isotopes produced. The thin bismuth targets were prepared by evaporation. The excitation curves were obtained using the stacked foil technique. The protons were accelerated as H_2^+ ions in the Argonne National Laboratory 60-inch cyclotron using the deuteron frequency. The deuterium contamination of natural hydrogen was removed magnetically after the H_2^+ ions were ionized to protons. The $\sigma_{(p,n)}/\sigma_{(p,\gamma)}$ ratio was approximately 10^3. The $(p,2n)$ threshold was found to be 9.78 ± 0.10 Mev.

SATURDAY MORNING AT 10:00

Rosenwald 2

(R. A. FISHER presiding)

Invited Papers

L1. The Effect of Pressure on Self-Diffusion of Sodium. N. H. NACHTRIEB, *University of Chicago.* (30 min.)

L2. The Chemisorption of Oxygen on Tungsten. ROBERT GOMER, *University of Chicago.* (30 min.)

General Physics

L3. A New Fluorescence Photometer. F. J. LYNCH, *Argonne National Laboratory.*—An instrument for measuring fluorescence is described which is sensitive, linear, and stable. Both an unknown and a standard fluorescent sample are irradiated with ultraviolet light from a mercury arc lamp operated on the 60-cps power line. Fluorescent light from each sample is incident on a separate vacuum phototube. The system automatically compares the 120-cps component of the photoelectric currents flowing in the two phototubes. In this way, the measurement is independent of intensity of the exciting ultraviolet source. Either solid or liquid samples may be rapidly measured. For uranium analysis the instrument may be calibrated to read 1000 divisions for 10^{-9}, 10^{-8}, 10^{-7}, or 10^{-6} μg of uranium. Although the fluorescence photometer is designed primarily for uranium analysis, the filters may be readily changed to permit measurements of other elements.

L4. Charge States of Ion Beams in Various Gases. P. M. STIER, C. F. BARNETT, AND G. E. EVANS, *Oak Ridge National Laboratory.*—Measurements have been made of the fraction of a heavy particle beam in the various possible charge states (neutral, singly, and doubly ionized), after passing through various gases. Ion beams, with energies from 10 to 250 kev, are passed through a windowless (differentially pumped) gas cell, and are electrostatically analyzed according to charge. The pressure in the stopping cell is sufficiently high to establish equilibrium between competing capture and loss reactions (i.e., the gas cell length is several mean free paths for charge exchange). This condition is compatible with the requirement that the fraction of the energy lost by the high-energy particle within the cell may be neglected. The incident ions H^+, He^+, N^+, Ne^+, and A^+ have been studied in the stopping gases, hydrogen, helium, nitrogen, oxygen, air, neon, and argon. The average charge of H^+ and He^+ ion beams after passing through a gas appears to be somewhat less than reported in the literature. No comparison data are available for the other ions at these energies.

L5. Some Characteristics of Gridded Parallel-plate Ionization Chambers. L. O. HERWIG, G. H. MILLER, AND N. G. UTTERBACK, *Iowa State College.*—Characteristics of a gridded parallel-plate ionization chamber employing electron collection were investigated by observing pulse height of alpha particles in various gases as a function of electrode voltages. The theoretical minimum ratio of collector to source fields for complete electron collection was 1.32 for the present geometry. Experimental values of the minimum ratio ranged from 2.2 for argon to 1.5 for argon plus 3 percent carbon dioxide. Correlation was found between calculated electron diffusion and observed minimum ratio of fields. Gas multiplication, presumably near the grid, was observed in argon and neon for X/P values of about 1.3 and 0.4, respectively, where X was calculated as a uniform field between the grid and collector electrodes. Saturation curves, pulse height *versus* source field, were obtained for argon, helium, nitrogen, neon, krypton, argon plus carbon dioxide, and argon plus nitrogen. Saturation properties of argon plus carbon dioxide, which gave faster drift velocities than argon, were found to be a function of mixture pressure and percentage of carbon dioxide. The use of argon-nitrogen mixtures, which also gave faster drift velocities, gave consistent saturation properties at pressures and percentages investigated.

L6. Use of a Pinhole for Producing Glow to Arc Transitions. B. PEARSON DELANY AND PAUL L. COPELAND, *Illinois Institute of Technology.* In studies of electrical discharges in mercury vapor at low pressure, the surface of a large mercury cathode has been separated into two areas.[1] A small area is divided from the rest of the pool by a glass tube of small diameter dipping into the mercury. This tube is flared and connected to the wall of the main tube by means of a ring seal. In such a tube, there is no discharge path between the large area of the cathode pool and the anode, because the glass wall of the constriction completely separates this portion of the cathode from the anode. If, however, a pinhole is left either in the ring seal or in the constriction above the mercury surface, at pressures of a few millimeters, when the potential of the anode is raised to set up a glow, it is always observed that a glow to arc transition occurs rapidly with an arc path passing through the pinhole to the area external to the constriction. Dependence of this phenomenon on pressure and circuit conditions has been studied.

[1] P. L. Copeland, Rev. Sci. Instr. **16**, 154 (1945).

L7. Stability of Low-Pressure Mercury Arcs with Positive Conducting Rod. J. T. KOUBA AND P. L. COPELAND, *Illinois Institute of Technology.*—Previous work with low-pressure mercury arcs has indicated that under fixed operating conditions the number of arcs surviving for time t plotted against t fell along curves of the form $\exp(-kt)$. The present study incorporated a high-resistance (approx. 20 000 ohms) carbon rod partially submerged in the cathode pool and electrically insulated from the plasma. The rod was subjected to a positive dc voltage and the average life determined as a function of rod voltage and cathode current. The experimental apparatus was set up so as to obtain a large amount of data in a reasonable amount of time. A switching circuit was devised so that after an arc extinguished an adjustable time delay allowed for data recording and then automatically ignited the arc by momentarily energizing a spark coil. It was found: (1) A positive conducting rod increases the stability somewhat, diameter rods being more effective. (2) The average life as a function of rod voltage can be expressed as $T_a = G \exp(hE_p)$; where T_a is the average life, G is a constant, h is a constant of the order 10^{-2} to 10^{-3}, and E_p is the rod voltage. (3) Spontaneous ignition took place erratically at $E_p = 200$ volts.

L8. Evapor-ion Pump.* AJAY S. DIVATIA, ROBERT H. DAVIS, AND R. G. HERB, *University of Wisconsin.*—The Evapor-ion Pump[1] which utilizes both the gettering action of titanium and ion pumping has undergone considerable

development and improvement. High pumping speeds and reasonable lifetime are obtainable with moderate power consumption. The pump chamber, free of organic materials, is baked out with a mechanical pump connected to it. It is then cooled and disconnected from the mechanical pump. Titanium, fed in a wire form onto a graphite post heated by electron bombardment, evaporates and condenses on the cylindrical chamber wall which is water-cooled to about 20°C. Gettering by continuously condensed titanium produces a pumping action. Components not pumped by this gettering are ionized and are driven into the chamber wall, where they are buried by the condensing titanium. Pumping speeds achieved are: 7000–8000 liters/sec at 3×10^{-6} mm of Hg for hydrogen, 6500–7500 liters/sec at 1.5×10^{-6} mm for nitrogen and oxygen, approximately 9 liters/sec at 4×10^{-6} mm for argon, and approximately 4 liters/sec at 3×10^{-5} mm for helium. The lowest pressure obtained is about 2×10^{-7} mm of Hg. Pumping speeds for some gases have been investigated as a function of the temperature of the gettering surface, the pressure and the rate of evaporation of titanium.

* Work supported by the Wisconsin Alumni Research Foundation and the U. S. Atomic Energy Commission.

[1] Herb, Davis, Divatia, and Saxon, Phys. Rev. **89**, 897 (1953).

L9. The Application of Solutions of Boltzmann Equation to Turbulence. M. Z. v. KRZYWOBLOCKI, *University of Illinois* (introduced by G. J. Plain).—The author discusses thoroughly the fundamentals underlying the derivation of Boltzmann equation, particularly the condition of the slowly varying distribution function and of the molecular chaos. Next he presents the available solutions of this equation: Hilbert, Enskog, Chapman, Burnett, and Grad. He points out the advantages and disadvantages of these solutions as well as the regions of their applicability in fluid dynamics. Next he discusses the application of these equations as the fundamental equations of the turbulent motion in the compressible fluid flow regime. The following items are treated more thoroughly: steady state of turbulence, transient one, and decay of turbulence.

L10. Velocity Attenuation of Explosive Produced Air Shocks. JACOB SAVITT, *U. S. Naval Ordnance Laboratory.*—The results of measurements of the velocities of explosive produced air shocks very close to the explosive-air interface will be presented. In tubes it was found that the data is consistant within certain limits with the semi-empirical relation, $1/U=1/U_0+Kd^2f_0X$, where U is the air shock velocity at the distance X in the air tube from the explosive-air interface, d is the cylindrical air tube internal diameter, f_0 is the undisturbed air density, and K is a constant. The origin of this equation, its limitations, and some of its application will be discussed.

SATURDAY MORNING AT 9:30

Kent 106

(H. L. ANDERSON presiding)

Mostly Elastic Scattering

M1. $P-P$ Differential Elastic Scattering Cross Sections at 144, 271, and 429 Mev. V. A. NEDZEL, J. MARSHALL, AND L. MARSHALL, *University of Chicago.*—The $P-P$ differential elastic scattering cross section at 90° baricentral angle has been measured for three proton energies and has been found to be independent of energy in this range. Sizable intensities of proton beams of a wide range in energy were obtained by the proper azimuthal positioning of a beryllium scattering target at 76 in. radius in the Chicago synchrocyclotron. The protons collimated by a channel in the heavy shield were of definite energy for a given target position. They were further analyzed by an additional magnet. The analyzed collimated beam was defined and measured before the scatterer by a telescope of 2 scintillation counters (1 and 2). The scatterer was a 4-in. vertical cylinder of liquid hydrogen contained in styrofoam walls. Two scintillation counters (3 and 4) were placed on opposite sides of the beam, connected in coincidence with counters 1 and 2 in such a way that they counted the two elastically scattered protons in coincidence with the incident proton. In order to avoid counting loss corrections, a fifth counter which counted protons scattered out of the main beam was used to normalize the incident flux at low-beam intensities and to normalize the quadruple coincidence rate at high beam intensity. The cross section at 90° was measured in millibarns per steradian as follows: 3.21 ± 0.11 at 144 Mev, 3.67 ± 0.34 at 271 Mev, and 3.42 ± 0.13 at 429 Mev.

M2. $P-P$ Elastic Scattering and Pion Production at 419 Mev. J. MARSHALL, L. MARSHALL, AND V. A. NEDZEL, *University of Chicago.*—The differential $P-P$ elastic scattering cross section at 419 Mev was measured from 90° to 54° baricentral angle by the method in which the two elastically scattered protons were detected in coincidence with the incident proton. From 54° to 28° a second method was used which counted all charged particles scattered at the angle in question in coincidence with an incident proton provided that no charged particle was simultaneously scattered near the forward direction. This method depended on several facts. First, the only reaction which seriously interferes with detection of scattered protons is (*a*) $P+P\rightarrow\pi^++D$. The related reaction (*b*) $P+P\rightarrow\pi^++P+N$ probably occurs less than 1/5th as frequently. In the case of (a) all deuterons and in the case of (b) many protons are scattered forward close to the beam. In a reversal of this method the π^+ production cross section at 45° laboratory angle was measured by counting charged particles scattered in coincidence with an incident proton and with a charged particle scattered simultaneously near the forward direction. By the first method were obtained the following cross sections in millibarns per steradian: 3.42 ± 0.13 at 90°, 3.51 ± 0.23 at 80°, 3.11 ± 0.19 at 65°, and 2.84 ± 0.12 at 54°. By the second method were obtained 2.80 ± 0.21 at 54°, 3.18 ± 0.21 at 43°, and 2.86 ± 0.20 at 28°. Correspondingly the differential π^+ production cross section at 80° was found to be 0.163 ± 0.024.

M3. A Search for Polarization of Protons from the 450-Mev Synchrocyclotron. L. MARSHALL, V. A. NEDZEL, AND J. MARSHALL, *University of Chicago.*—Maximum polarization of a scattered proton beam from the internal beryllium target was sought. By proper selection of the azimuthal target position, the first scattering angle θ_1 and the energy of protons emerging into the experimental area through the heavy shield collimator were chosen approximately equal to the angle and energy of a proton scattered from a free nucleon-nucleon collision. The

collimated beam was further analyzed by magnetic deflection. Beam polarization should have shown itself as an asymmetry of a second scattering from beryllium in the plane of the first scattering. Protons scattered at 30° up, down, left, and right were measured with detection equipment swung around the beam. The counter support was oriented to beam coordinates previously determined by counter exploration. Two different methods were used to search for asymmetry. In the first method (a) only protons scattered as though from a free $p-p$ or $p-n$ collision in the beryllium nucleus were detected. The second method (b) examined only protons scattered from $p-p$ collisions. The background was about 5 percent. No asymmetry was evident. The results are for (a) $\theta_1=36°$ left, $\theta_2=30°$, up-down asymmetry $=-(3\pm6)$ percent, right-left asymmetry $=-(0.005\pm6)$ percent, and for (b) $\theta_1=36°$ left, $\theta_2=30°$, right-left asymmetry $=-(5\pm6)$ percent; $\theta_1=26°$ right, $\theta_2=30°$, right-left asymmetry $=+(2.7\pm3.0)$ percent.

M4. The Elastic Scattering of Protons by Nitrogen. H. E. Gove, A. J. Ferguson, and J. T. Sample, *Chalk River Laboratory.*—The elastic scattering of protons by nitrogen has been studied in the range 1.3 Mev to 1.9 Mev using the Chalk River electrostatic accelerator. A gas target was used in a large scattering chamber similar to that described by Blair *et al.*[1] There are three resonances in this region at energies 1.53, 1.72, and 1.78 Mev. Angular distributions were determined by measuring the scattered intensity at eleven different angles in the range 50° to 153°, at about ten different energies near the resonances. From these it is concluded that the spin and parity assignment for the 1.53 Mev resonance is $\frac{1}{2}(+)$ with only the channel spin $\frac{1}{2}$ contributing. The 1.72-Mev resonance is not adequately resolved in energy, but a probable assignment of $\frac{3}{2}(-)$ with only channel spin $\frac{1}{2}$ contributing has been made. Throughout the energy range there is a "background" scattering markedly different from pure Coulomb scattering, and showing larger S-wave and smaller P-wave phase shifts than predicted from hard sphere scattering.

[1] Blair, Freier, Lampi, Sleator, and Williams, Phys. Rev. **74**, 553 (1948).

M5. Differential Cross Sections for the Elastic Scattering of Protons by He^3.† K. F. Famularo, R. J. S. Brown, H. D. Holmgren, and T. F. Stratton, *University of Minnesota.*—Differential cross sections for protons elastically scattered from He^3 have been measured at laboratory energies of 1.01, 1.60, 2.25, and 3.52 Mev for nine center-of-mass angles extending from 36° to 169°. Also, the differential cross sections at center-of-mass angles of 44° and 169° have been measured in 30-kev steps for proton energies from 0.7 Mev to 3.5 Mev. The small volume scattering chamber and associated equipment used for these measurements have been described earlier.[1,2] The cross section at 1.01 Mev has a constant value of 0.12 barns/sterad for center-of-mass angles greater than 90°, and approaches the values expected from Coulomb scattering at lower angles. At 1.60, 2.25, and 3.52 Mev, the angular distributions have broad minima whose values are 0.11, 0.09, and 0.08 barns/sterad, respectively, in the neighborhood of 90° (center of mass). The cross section at 169° increases from 0.11 barns/sterad at 0.9 Mev to 0.27 barns/sterad at 3.5 Mev.

† Assisted by the joint program of the U. S. Office of Naval Research and U. S. Atomic Energy Commission.

[1] Brown, Freier, Holmgren, Stratton, and Varnell, Phys. Rev. **88**, 253 (1952).

[2] Stratton, Freier, Keepin, Rankin, and Stratton, Phys. Rev. **88**, 257 (1952).

M6. Elastic Scattering of Deuterons by Helium.* A. Galonsky, R. Douglas, W. Haeberli, M. McEllistrem, and H. T. Richards, *University of Wisconsin.*—$He^4(d,d)$ differential cross sections were measured from 0.3 to 4.6 Mev with a differentially pumped gas scattering chamber. A resonance with peak cross section at $E_d=1.076$ Mev (for 173.6° c.m.) and $\Gamma\sim35$ kev was observed at 9 angles from 90° to 173.6° c.m. The cross section at 90° c.m. drops from 0.20 to 0.07 rising again to 0.14 barns/sterad; this dip indicates even parity for the 2.187-Mev state of Li^6. Data at 3-kev intervals were taken in the region of the 3.58-Mev state. No anomaly being observed agrees with the assignment $J=0^+$, $T=1$. Conservation laws do not permit the formation of such a state with a deuteron and an α particle. The cross section curves are flat above the 1.076-Mev resonance up to 3 Mev. Above 3 Mev the 173.6° c.m. cross section rises from 0.1 to 0.5 barns/sterad at 4.6 Mev while the 90° c.m. cross section drops by about a factor of two. Further analysis is in progress.

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.

M7. Neutron-Proton Scattering at 395 Mev.—I.* A. J. Hartzler and R. T. Siegel, *Carnegie Institute of Technology.*—The equipment used in a study of differential $n-p$ scattering (see following abstract) will be described. Recoil protons ejected from hydrogen (CH_2-C difference) were detected by a three-crystal scintillation telescope. To make the apparatus insensitive to recoils from incident neutrons of less than 365 Mev, a variable copper absorber was placed between the last two counters. Calibration of the telescope to determine the loss of protons in the absorber was done in an auxiliary experiment, in which the external proton beam from the synchrocyclotron was scattered in proton-proton collisions with the same geometry and scatterers used in the measurement of the neutron-proton cross section. In the calibration experiment the recoil protons were counted both by the double coincidences between the first two counters and also by triple coincidences. The ratio of the two counting rates gives the telescope efficiency, while the variation of double coincidences with angle yields some information about the differential $p-p$ cross section. The method is also used in determining the neutron spectrum from a range curve of the neutron-proton recoils.

* Supported in part by the U. S. Atomic Energy Commission.

M8. Neutron-Proton Scattering at 395 Mev.—II.* R. T. Siegel and A. J. Hartzler, *Carnegie Institute of Technology.*—The equipment described in the preceding abstract has been used to study the neutron-proton angular distribution, using the neutron beam of the Carnegie cyclotron. The effective neutron spectrum had a mean energy of 395 Mev with a full width at half-maximum of 40 Mev, and intensity of $\sim10^5$ cm^{-2} sec^{-1}. Recoil protons from polyethylene-carbon differences were detected at eighteen laboratory angles between 0° and 68°, corresponding to neutron scattering angles between 40° and 180° in the center-of-mass system. Angular resolution for c.m. angles between 40° and 160° was ~7°, and was improved to 3.5° for angles between 160° and 180°. Statistical errors of <5 percent were obtained at all angles except 180°, where further measurements are in progress. Our results indicate a deviation from symmetry about 90°, with a minimum in the cross section at ~100°. The ratio of the cross sections at 175° and 90° is ~7, indicating a strong peak at 180°. Detailed results will be presented.

* Supported in part by the U. S. Atomic Energy Commission.

Invited Paper

M9. Elastic Scattering of Positive and Negative Electrons from Nuclei. P. S. Jastram, *Washington University.* (30 min.)

M10. Double Scattering of Protons at High Energies. C. L. Oxley, *University of Chicago.* (30 min.)

SATURDAY MORNING AT 9:30

Oriental Institute

(A. S. EISENSTEIN presiding)

Electron Physics; Thin Films

N1. Luminescent Centers in X-Ray Excited Fluorescence of Ice. L. I. GROSSWEINER AND M. S. MATHESON, *Argonne National Laboratory.*—The emission spectrum of x-ray excited ice at low temperatures is shifted in wavelength and intensified by the presence of ionic additives. The intensification increases with additive concentration and saturates at about 0.01 molar for sodium chloride. The spectral shifts are specific to the cation of the additive. A luminescent model is proposed in which the primary process is the radiative capture of electrons by additive cations. Approximate emission energies calculated from a thermodynamic cycle agree with those obtained experimentally. For the monovalent cations the emission energies are substantially given by the difference of the corresponding atomic ionization potentials and the heats of solvation of the ions in ice. This suggests that the reciprocals of the average emission energies should vary with the cationic radii of the additives. The correlation is valid for the additives tested.

N2. Electroluminescence with Nonsinusoidal Electric Fields. SOL NUDELMAN AND FRANK MATOSSI, *U. S. Naval Ordnance Laboratory.*—A variety of luminescent wave shapes were obtained when electric fields in the form of rectangular pulses, saw-tooth waves, exponential waves, and various nonsymmetrical waves were applied to an electroluminescent phosphor. The luminescent patterns observed were examined separately in the blue and green bands by means of filters. In general, the character of the light output from the phosphor was independent of whether the applied field was reversed every half cycle or pulsed unidirectionally. The phosphor light output can be interpreted qualitatively by considering (1) the growth and decay of the effective field caused by space charges near the particle surface, (2) the natural decay of the blue and the green luminescence, and (3) the different efficiency of excitation of the two colors. Luminescence excitation is assumed to be caused by some collision process with field-accelerated electrons; the efficiency depending on field strength, number of conduction electrons, and number of excitable centers. The green luminescence is supposed to involve transitions from the conduction band and traps, while the blue band is assumed to be due to transitions within the centers only.

N3. Electroluminescence in ZnS:Mn Films. R. E. HALSTED AND L. R. KOLLER, *General Electric Research Laboratory.*—Ten micron films of ZnS phosphors which will withstand voltage gradients approaching 5×10^5 v/cm have been prepared by vapor reaction techniques. Qualitative experiments with ZnS:Mn films reveal excitation, emission, and photoconductivity characteristics of conventionally prepared ZnS:Mn phosphors. Variations from previously reported results for other phosphors in the electroluminescent emission and its dependence on voltage, frequency, and temperature will be presented.

N4. Photoinduced Conductivity in Solutions of Anthracene in *n*-Hexane.* L. W. AUKERMAN, *Purdue University.*—Dilute solutions (approx. 5×10^{-4} to 5×10^{-3} M) of purest anthracene in carefully purified *n*-hexane show a conductivity in the dark of less than 10^{-17} mho/sec (measured with a vibrating reed electrometer). Illumination near 1950 A produces an increase in conductivity up to several hundred times the dark conductivity, thus verifying the results of Volmer.[1] The behavior of this "photocurrent" indicates that the additional carriers are produced in the bulk of the liquid by light which is absorbed by the anthracene molecules. By measuring the photocurrent as a function of light intensity, as a function of concentration of the anthracene, and as a function of time, one must conclude that ions are formed with mobilities of the order of 5×10^{-4} cm²/volt-sec. The current i as a function of light intensity I is given by $i=a+b\sqrt{I}$.

* This work supported in part by the Office of Naval Research.
[1] M. Volmer, Ann. Physik **40**, 775 (1913).

N5. Photoconductivity of Single Crystals of Anthracene.* G. J. GOLDSMITH, *Purdue University.*—Photoconductivity in single crystals of anthracene has been observed with crystals illuminated in the near ultraviolet (threshold near 4000A) and the spectral dependence of photocurrent corresponds to the optical absorption. The photocurrent i depends on intensity I as $i=aI^{0.7}$. The field dependence of photocurrent does not show saturation with fields up to 10 000 volts/cm in vacuum. From the experiments we conclude that both electrons and holes participate in the conduction process. An oxygen atmosphere causes an increase in the conductance both in the dark and in the light. The dark conductance (σ_d) can be described as $\sigma_d=\sigma_0 e^{-\epsilon/2kT}$ with ϵ about 1.60 ev.[1]

* This work supported in part by the U. S. Office of Naval Research.
[1] H. Mette and H. Pick, Z. Physik **134**, 566 (1953). These authors give $\epsilon=1.65$ ev.

N6. Energy Distribution of Secondary Electrons from Solids. ERNEST J. STERNGLASS,* *Cornell University.*—Measurements of the energy distribution of the secondary electrons from Au, Pt, Ta, Cu, and C under bombardment by 0.2–2.5-kv electrons have been made using a spherically symmetric retarding field. When corrected for the high energy (>50 ev) backscattered fraction, the form of the energy distribution and the values of the most probable and median energies were found to be the same for all materials to ±1 ev, independent of primary energy. The shape of the curves and the location of the most probable and mean values agree closely with data on air and H_2,[1] except for a small excess between 10 and 15 ev and a more rapid decrease beyond 25–30 ev found for all solids relative to the gases. Similar features, explainable by discrete energy losses, have been observed by previous investigators for Mo and Ta. The similarity of the curves for all substances independent of their state of aggregation is in agreement with the dominant role of bound electrons as demanded by the author's theory of secondary emission.[2]

* Now at Westinghouse Research Laboratories.
[1] M. Ishino, Phil. Mag. **32**, 202 (1916).
[2] Thesis, Cornell University, February, 1951; also summary in Report on 13th Annual Electronics Conference, Massachusetts Institute of Technology, 1953.

N7. A Study of SrO on Mo by Use of the Field Emission Microscope.* P. W. KRUSE AND E. A. COOMES, *University of Notre Dame.*—Observations of the migration of SrO over a Mo point have been made by means of the field emission microscope technique. An etched Mo point mounted in a Mueller tube[1] was flashed until a reproducible pattern, similar to that obtained by Becker[1] for clean W, was observed. SrO evaporated from a Pt ribbon source[2] was deposited in varying amounts on one side of the point. On heating the point to approximately

1200°K in the presence of a field of about 10^8 volts cm^{-1}, migration was complete within 17 minutes, with a tendency to build up in the 221 region. On heating in the absence of a field migration rates were similar, but there were differences in the migration patterns.

* Sponsored by the U. S. Navy Bureau of Ships.
[1] J. A. Becker, Bell System Tech. J. **30**, 907 (1951).
[2] G. E. Moore and H. W. Allison, Phys. Rev. **77**, 246 (1950).

N8. Effect on the Periodic Schottky Deviations Resulting from a SrO Layer Deposited on Clean Molybdenum.* G. A. HAAS† AND E. A. COOMES, *University of Notre Dame.*—Periodic deviations in the Schottky effect for a polished polycrystalline Mo filament have been compared for the clean state and states corresponding to monomolecular coverage with SrO. Deviations for the clean state were of the usual form;[1] agreement was found for the mirror image λ coefficient, but not for the box-model μ coefficient. The Schottky plot for this filament had a long patch free region, which allowed an accurate study of deviation amplitude as a function of temperature. The inverse temperature dependence in accordance with theory[2] was found for the 1500–1700°K range. When SrO was deposited the periodic deviations disappeared; as little as 1/100 monolayer coverage made the deviations unobservable, and at approximately $\frac{1}{3}$ monolayer coverage deviation from the Schottky line was less than 0.01 percent.

* Sponsored by the U. S. Navy Bureau of Ships.
† Now at the Naval Research Laboratory, Washington, D. C.
[1] Brock, Houde, and Coomes, Phys. Rev. **89**, 851 (1953).
[2] E. Guth and C. Mullin, Phys. Rev. **59**, 575 (1941).

N9. The Electrical Resistances of Dual Layer and Simultaneously Evaporated Bimetal Films before and after Artificial Aging.* RICHARD B. BELSER AND MARGARET C. CHESTER, *Georgia Institute of Technology.*—Bi-metal films of a number of metal pairs have been deposited on glass substrates in two successive layers, with the layer order reversed, and by simultaneous evaporation. The resistances of the latter were several times those of dual layer films of equivalent metals and thickness. After aging by heating in an infrared vacuum oven, the resistances of the simultaneously evaporated films were usually reduced by factors of 2–10 whereas those of the dual layer films appeared to behave in accordance with the alloying characteristics of the metal pair. Where intermetallic compounds or solid solutions were readily formed rapid resistance rises after aging at temperatures of 100–150°C were noted. Where the alloying action was of a less degree, a reduction in resistance was frequently noted on aging followed by a rise in resistance of more moderate slope on further heating. Where no appreciable alloying occurred, resistances were decreased by aging until aging temperatures of 500°C were exceeded. X-ray diffraction and micrographic studies of the same samples were made. The techniques described may allow observation of the diffusion and alloying characteristics of minute amounts of metals.

* Supported by U. S. Army Signal Corps.

N10. X-Ray Diffraction Studies of Dual Layer and Simultaneously Evaporated Bimetal Films After Artificial Aging by Heating.* WILLIAM E. WOLF AND RICHARD B. BELSER, *Georgia Institute of Technology.*—The bimetal films described in the previous paper have been examined by x-ray methods similar to those employed by Burr, Coleman, and Davey.[1] Results using a recording Geiger counter spectrometer were generally unsatisfactory because of the high background due to scattering by the glass substrate. More satisfactory results were obtained when the metal was scraped from the glass substrate and used as the sample in a Hull-Debye-Scherrer camera. Using this technique the various phases present could be identified. In addition, it was possible to determine that for certain specimens the time of heating had been insufficient to allow complete diffusion of the metals. In some cases, in which the phase diagram is unknown, the presence of lines not attributable to the two elements indicated the presence of new phases. The x-ray data, in general, confirm the observations regarding the alloying characteristics and diffusion of metals made during the resistance studies. The method appears to offer promise as a means of obtaining partial x-ray information on the binary systems of rare or precious metals.

* Supported in part by the U. S. Army Signal Corps.
[1] Burr, Coleman, and Davey, Trans. Am. Soc. Metals **33**, 73 (1944).

N11. Metallographic Studies of Dual Layer and Simultaneously Evaporated Bimetal Films After Artificial Aging by Heating.* ROBERT J. RAUDEBAUGH AND RICHARD B. BELSER, *Georgia Institute of Technology.*—In conjunction with resistivity and x-ray diffraction studies of dual layer and simultaneously evaporated metal films a number of metallographic observations have been made. Micrographs taken of gold-indium and iron-indium films after various stages of artificial aging are discussed. Some interesting effects have been observed. For gold and indium, simultaneously evaporated and heated to 350°C, a spectacular dendritic structure appeared. For iron, overcoated with indium, the indium film aggregated into globules upon the surface of the iron at a temperature of 190°C. These two cases respectively represent examples of vigorous alloying and apparent mutual insolubility of the component metals. Utilization of the techniques herein described appears to offer a means of making metallographic studies of alloys with minute quantities of metals and a minimum preparation of the surfaces. Further work on etch techniques and interpretation of observations are necessary before this procedure may be considered a method of real value for the study of unknown binary systems.

* Supported in part by the U. S. Army Signal Corps.

SATURDAY MORNING AT 9:30

Mandel Hall

(ENRICO FERMI presiding)

Invited Papers

P1. Photomesons Near the Production Threshold. GILBERTO BERNARDINI, *University of Illinois.* (30 min.)

P2. Reports on the Cosmic-Ray Conferences Held in July, 1953, at Bagnères-de-Bigorre. (a) Conference on Intensity-Time Variations. J. A. SIMPSON, *University of Chicago.* (b) Conference on Fundamental Particles. MARCEL SCHEIN, *University of Chicago.* (60 min. to be divided between the two speakers).

P3. Evidence for the Existence of the V_4 Particle. R. W. THOMPSON, *Indiana University.* (30 min.)

P4. Theoretical Speculations about New Unstable Particles. MURRAY GELL-MANN, *University of Chicago.* (30 min.)

SATURDAY AFTERNOON AT 1:30

Kent 106

(JOHN MARSHALL presiding)

Neutrons, and Other Topics in Nuclear Physics

Q1. Scattering of Polarized Neutrons from Heavy Nuclei.* S. E. DARDEN, R. E. FIELDS, AND R. K. ADAIR, *University of Wisconsin.*—The polarization P_1 of $Li^7(p, n)$ neutrons emitted at 50° in the laboratory system was measured at a neutron energy around 400 kev, using liquid oxygen as an analyzer. The level parameters of the 435-kev oxygen resonance are sufficiently well known to allow calculation of P_1 from the measured 90° left-right scattering asymmetry. The scattering asymmetry was then observed using thirteen heavy elements as analyzers. From these measurements the polarization P_2 produced by the heavy elements was inferred. Values of P_2 around 20 ± 5 percent were found for nuclei with A around 100, while lighter and heavier elements gave no measurable polarization. These results can be accounted for by adding a term of the form -2 Mev $(\mathbf{l}\cdot\mathbf{s})$ to the complex potential proposed by Feshbach, Porter, and Weisskopf.[1]

* Work supported by the U. S. Atomic Energy Commission and the Wisconsin Alumni Research Foundation.
[1] Feshbach, Porter, and Weisskopf, Phys. Rev. **90**, 166 (1953).

Q2. Polarization of Neutrons. C. P. STANFORD, T. E. STEPHENSON, L. W. COCHRAN, AND S. BERNSTEIN, *Oak Ridge National Laboratory.*—The neutron polarization cross section of iron has been measured as a function of energy from 0.7 to 3.3A by two methods: using the single transmission effect in a block of polycrystalline iron at energies selected by a quartz crystal monochromator; using a single crystal of magnetized magnetite to analyze the beam emerging from the iron polarizer, the magnetite crystal itself serving as monochromator. The measured values are compared with those of other observers and the theoretically expected values. These are found to agree fairly well within the limits of accuracy of the measurements and existing knowledge of the wave function of the iron 3*d* shell. The two techniques were used also to determine the average polarization (32 percent) as seen by a $1/v$ detector in a beam of reactor neutrons emerging from a 4 cm thick polarizing block of iron.[1] Problems and techniques associated with the measurement of the average polarization of a continuous spectrum are discussed. A simplified experimental treatment of the problem of beam "hardening" is described. A description is given of the use of the magnetic resonance method in conjunction with a single crystal magnetite analyzer for the measurement of neutron polarization.

[1] This information is pertinent to an associated project on the capture of polarized neutrons by polarized nuclei.

Q3. Recent Measurements on the Lowest Neutron Scattering Resonance in Cobalt. F. G. P. SEIDL, *Brookhaven National Laboratory.**—Using the Brookhaven fast chopper, the variation of neutron transmission $T(E)$ with energy E has been measured for two thicknesses of cobalt. The energy range included the lowest cobalt resonance, and the resonance peak was observed at 134 ± 2 ev which is somewhat higher than has been published previously.[1] The effect of experimental resolution was largely eliminated by considering the integral over energy of $1-T(E)$; this can be expressed in terms of a single-level Breit-Wigner formula. Previous experiments[2] have shown this resonance to be predominantly scattering; accordingly, by assuming the resonance to be entirely scattering, a peak cross section may be computed for each of the two possible spin states. One of these is consistent with the measurements on each thickness; i.e., $j=3$ for the compound nucleus. The corresponding level width comes out $\Gamma=5.5\pm0.5$ ev. No corrections were made for Doppler broadening which is $\Delta=0.48$ ev, Δ being the half-width at $1/e$ of maximum.

* Work carried out under contract with the U. S. Atomic Energy Commission.
[1] W. W. Havens, Jr., and L. J. Rainwater, Phys. Rev. **83**, 1123 (1951); A. W. Merrison and E. R. Wiblin, Proc. Roy. Soc. (London) **A215**, 278 (1952).
[2] F. G. P. Seidl, Phys. Rev. **75**, 1508 (1949); Harris, Muehlhause, and Thomas, Phys. Rev. **79**, 11 (1950).

Q4. Doppler Effect in the Slow Neutron Resonance of Rhodium.* H. H. LANDON, *Brookhaven National Laboratory.*—The variation in transmission of a rhodium foil to 1.26-ev neutrons has been measured as a function of foil temperature using the BNL crystal spectrometer. A change in transmission of approximately two percent per 100 degree temperature change has been observed over a temperature range from 120°K to 860°K. After correction for instrument resolution and Doppler, a peak cross section of 4850 ± 200 barns results as compared to the predicted $\sigma_0=5000\pm200$ barns of Sailor.[1] Comparison with the theory of Bethe and Placzek[2] as extended by Lamb[3] will be made.

* Research supported by the United States Atomic Energy Commission.
[1] V. L. Sailor, Phys. Rev. **91**, 53 (1953).
[2] H. A. Bethe and G. Placzek, Phys. Rev. **51**, 450 (1937).
[3] W. E. Lamb, Jr., Phys. Rev. **55**, 190 (1939).

Q5. Determinstion of Scattering Resonance Parameters from the Total Cross Section. W. Y. KATO,* D. J. HUGHES, AND J. S. LEVIN, *Brookhaven National Laboratory.*†—An analysis has been devised to obtain $g\Gamma_n$ from the total cross section of a resonance even when capture predominates. It is found possible to determine $g\Gamma_n$ by measuring the variation of the total cross section with energy away from resonance where the interference effect from resonance and potential scattering predominates. The interference or cross-term effect decreases as $1/\Delta E$ whereas the resonance effect decreases as $1/\Delta E^2$, therefore, this analysis may be used even though the resonance is mostly capture. The value $g\Gamma_n$ for the 4.90-ev level in Au has been determined to be 8.6×10^{-3} ev in reasonable agreement with the value of 10×10^{-3} ev obtained by Landon and Sailor.[1] For the 7.75-ev level in Hf^{178} Γ_n has been found to be 55×10^{-3} ev which is in good agreement with the value obtained by using a thick and thin sample analysis. The present method is applicable for relatively isolated resonances and can be used at energies where insufficient resolution renders the usual methods inapplicable.

* Now at Argonne National Laboratory, Lemont, Illinois.
† Work carried out under contract with the U. S. Atomic Energy Commission.
[1] H. Landon and V. Sailor (private communication).

Q6. Neutron Binding Energy in Bi^{210}. C. G. ANDRE AND J. R. HUIZENGA, *Argonne National Laboratory.*—Several authors[1] have suggested that the 0.5-Mev energy discrepancy in the closed energy cycle, $Po^{210}-Pb^{206}-Pb^{207}-Pb^{208}-Pb^{209}-Bi^{209}-Bi^{210}-Po^{210}$, results from the measured neutron binding energy in Bi^{210} [from (d, p) and (n, γ) reactions in Bi^{209}] being underestimated. Therefore, an independent value of the binding energy of a neutron in Bi^{210} is calculated from the experimental $Bi^{209}(p, 2n)Po^{208}$ threshold[2] and existing decay data. It can be shown readily that, $E_n(Bi^{210})=E_{n-\gamma}1(0.78)+E_n(Tl^{205})+E_n(Tl^{206})+E_\beta(Tl^{206})+E_\alpha Po^{208}-E_\alpha Po^{210}$

$-E_\beta(\mathrm{Tl}^{204})-E_\beta(\mathrm{Bi}^{210})-E_{T\alpha}[\mathrm{Bi}^{209}(p,\ 2n)\mathrm{Po}^{208}]$. Substitution of the best available data in this equation gives a value of 4.19 ± 0.16 Mev for the Bi^{210} neutron binding energy.

[1] Huizenga, Magnusson, Simpson, and Winslow, Phys. Rev. **79**, 908 (1950); Kinsey, Bartholomew, and Walker, Phys. Rev. **82**, 380 (1951); J. A. Harvey, Can. J. Phys. **31**, 278 (1953).
[2] Andre, Ramler, Rauh, Thorn, and Huizenga (previous abstract).

Q7. Direct Integration of the Neutron Transport Equation.* J. HELLER AND H. KELLER, *New York University.*—The distribution of neutrons in a moderator or shield is governed by the Boltzmann equation which, under assumptions which are frequently valid, reduces to the transport equation. It is proposed to solve this equation directly, for some simple one-dimensional geometries, with the aid of a high-speed digital computer. In particular we are first considering a plane shield of finite thickness symmetrically placed about a plane fission spectrum source of zero thickness. The shield may consist of several regions each of which is composed of different compounds. It seems probable that the method is applicable to spherical regions and could be adapted to reactor problems.

* This work is being carried on at the U. S. Atomic Energy Commission Computing Facility at New York University.

Q8. Nuclear Energy Surface and Isotopic Mass Values. J. R. STEHN, *Knolls Atomic Power Laboratory.**—Based on isotopic masses and radioactive decay schemes, a plot has been made of nuclear mass M *vs* charge Z for each total nucleon number A and the position of the minimum estimated to be at Z_0. Z_0 is a smooth function of A, the values lying on the same curve whether from even-even, odd-odd, or odd A nuclides. The over-all plot of $Z_0(A)$ shows bends at the expected closed shells where Z or N is 20, 28, 50, 82, or 126 and shows irregularities near $Z=41$, $N=54$, $Z=64$, and $N=85$ which may be merely the result of incorrect nuclear data or assignments. This plot is the basis of the line of maximum beta stability on the General Electric Chart of the Nuclides. Since actual stable nuclides are seldom at the exact minima of M *vs* Z curves, and since there are well-known effects differentiating even-even, odd-odd, and odd A nuclides, experimentally measured packing fractions are bound to vary somewhat irregularly with mass number. A smoothed-out packing fraction curve, adjusting the foregoing effects to fit the minima of the even-even nuclides, will be shown.

* Operated by the General Electric Company for the U. S. Atomic Energy Commission.

Q9. Harmonic Mean Energy of the Nuclear Photoeffect. J. S. LEVINGER, *Louisiana State University.*—Levinger and Bethe[1] used sum rules to determine the harmonic mean energy for electric dipole photon absorption as

$$W_H = 5\hbar^2/2MR^2 = 50A^{-\frac{1}{3}}\ \text{Mev},$$

assuming ordinary forces between the nucleons and no correlations among the nucleons. This value is considerably smaller than that calculated from Burkhardt's results[2] based on the independent particle model (IPM) for neutrons in Cu^{63}. The discrepancy is the result of correlations, present even in the IPM, caused by the Pauli exclusion principle. Calculations with a Fermi gas model show that Pauli principle correlations increase the sum-rule value of W_H by about a factor of two. Calculations of W_H for several nuclei are in progress using IPM wave functions for a square well. A similar discrepancy between the sum-rule results and the direct calculation of $\bar{W}$ is also resolved by including the Pauli principle correlations in the sum-rule calculation.

[1] J. S. Levinger and H. A. Bethe, Phys. Rev. **78**, 115 (1950).
[2] J. L. Burkhardt, Phys. Rev. **91**, 420 (1953).

Q10. Ionization Yields for Fission Fragments. GLENN H. MILLER AND LLOYD O. HERWIG, *Iowa State College.*—Fission fragment mass and velocity distributions previously derived from data obtained from double ionization chambers using argon plus CO_2 disagree with other measurements of these distributions.[1] These differences were explained in terms of an ionization defect for argon. The ionization defect is thought to result from energy transfer through elastic collisions and hence should be a function of the atomic mass of the gas. In this experiment, an investigation was made of the relative defects in He, Ne, A, Kr, A plus CO_2, and A plus N_2. Ionization distributions were obtained for fission and alpha particles using a parallel-plate gridded chamber employing electron collection. A natural uranium film was irradiated with $d-d$ reaction neutrons. Comparison of the most probable pulse voltages for fission fragments with those of alpha particles, combined with known alpha energies, gave the so-called fission energies. These energies and associated defects are presented for the gases mentioned. It appears that part of the defect previously attributed to pure argon may be the result of molecular effects of small percentages of CO_2 customarily added to argon.

[1] R. B. Leachman, Phys. Rev. **87**, 444 (1952).

Q11. Origin of Anomalous Abundances of the Elements in Giant Stars. A. G. W. CAMERON, *Iowa State College.*—Following the exhaustion of hydrogen in a giant star, the core is expected to contract and the central temperature to rise until thermonuclear reactions with the helium set in. At approximately 1×10^8 °K the reaction $C^{13}(\alpha, n)O^{16}$ will proceed rapidly. It is assumed that C^{13} has an equilibrium abundance of about 20 percent of the carbon plus nitrogen nuclei in the Bethe cycle in order to explain the large carbon abundance in stars with R and N spectra. The resulting neutrons will be captured by the surrounding material in proportion to the products of cosmic abundances times capture cross sections (at $E_n\sim10$ kev). The latter quantities are poorly known in the most abundant light elements, but a crude calculation gives the formal result that a typical heavy nucleus ($A\sim100$) will capture about 20 neutrons. The "magic number" nuclei Sr^{88}, Y^{89}, Zr^{90}, Ba^{138}, La^{139}, Ce^{140}, Pr^{141}, Nd^{142}, and Pb^{208} will act as sinks for the collection of heavy nuclei. Most of these elements have been observed to have anomalously large abundances in stars with S spectra and in "BaII" stars. The formation of a large amount of technicium (observed in some S spectra) in equilibrium with neighboring elements also follows from this theory.

Q12. Annihilation of Positrons in Flight.* H. W. KENDALL AND MARTIN DEUTSCH, *M.I.T.*—The cross section for annihilation of positrons in flight has been measured for positron energies of 0.765, 1.02, 2.2, and 3.33 Mev. The method used was basically that of Shearer and Deutsch.[1] Positron energies were selected by means of a magnetic lens monochromator and a differential energy interval of about 0.1 Mev defined by the pulse height from an anthracene crystal in which the positrons were annihilated. The annihilation radiation was detected in a scintillation counter biased to record only quanta above 0.51 Mev. The angular distribution of the annihilation radiation is in good agreement with that given by Heitler,[2] modified by the scattering of the positrons in anthracene. The total differential cross section at all energies agrees with the theoretical value[2] within the accuracy of the experiment, estimated to be about ±5 percent.

* This work was assisted in part by the joint progrm of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. W. Shearer and M. Deutsch, Phys. Rev. **82**, 336 (1951).
[2] W. Heitler, *The Quantum Theory of Radiation* (Oxford University Press, Oxford, 1944), pp. 204–208.

Q13. The Čerenkov Effect and the Dielectric Constant. S. M. NEAMTAN, *University of Manitoba.*—A quantum mechanical theory of the Čerenkov radiation is developed wherein the refractive medium is treated not as a continuum, but as an

aggregation of atoms. The atoms and the electromagnetic field are considered as forming a single system which interacts with an incident charged particle. The Čerenkov radiation arises in first-order transitions induced by this interaction. The nature of this process suggests a quantum mechanical definition of the dielectric constant with the aid of which the theory yields the well-known properties of the Čerenkov radiation. The definition of the dielectric constant is shown to lead to the same expression for this quantity as is given by the Kramers-Heisenberg dispersion formula.

SATURDAY AFTERNOON AT 1:30

Eckhart 133

(R. S. MULLIKEN presiding)

Invited Paper

R1. Isotope Shift in the Spectra of Some Elements of Intermediate Atomic Number. HACK ARROE, *University of Wisconsin.* (30 min.)

Optical and Chemical Physics

R2. The Continuous Emission Spectra of Kr and Xe in the Vacuum Ultraviolet Region. YOSHIO TANAKA AND MURRAY ZELIKOFF, *Air Force Cambridge Research Center.*—Using the Ratheon Manufacturing Company's "Microtherm" as a power supply, we studied the emission spectra of Kr and Xe in the vacuum ultraviolet region. When the pressure was increased to about 10 mm Hg, the first resonance lines of these elements (Kr, 1236A; Xe, 1470A) were considerably broadened towards the longer wavelength side, that is, to about 1330A and 2200A, respectively. For the emission mechanisms of the continua, the same explanation can be applied as in the case of absorption of the resonance lines of Xe which was observed by McLennan and Turnbull.[1]

[1] J. C. McLennan and R. Turnbull, Proc. Roy. Soc. (London) **A129**, 266 (1930); **133**, 683 (1933).

R3. Forbidden Line in the Spectrum of PI. S. MROZOWSKI, *University of Buffalo.*—The spectrum of PI was excited by high-frequency oscillations in presence of several millimeters of helium gas. The pressure of the vapor was varied by heating an appendix containing highly purified red phosphorus. The experiments were undertaken to check the feasibility and limitations of this method for excitation of spectra in light elements. Difficulties were experienced due to an exceedingly strong emission of the molecular spectrum of PO (bands around λ6390, 5960, 5580, and 5250, observed previously in a flame spectrum by Rump and others) at slightest contaminations. When the impurities were eliminated the line λ5333 [$^2P_{\frac{1}{2}}^0 \rightarrow {}^4S_{\frac{3}{2}}^0$ both levels belonging to the configuration $(3p)^3$] was identified in the spectrum and found to be emitted with a reasonably high intensity ($\frac{1}{2}$-hr exposures on a Bausch & Lomb spectrograph) at vapor pressures for which the PI spectrum begins to weaken giving way to the molecular (P_2) emission. The line $^2P_{\frac{1}{2}}^0 \rightarrow {}^4S_{\frac{3}{2}}^0$ does not appear on these spectrograms, this being in agreement with the general trend as observed in the corresponding spectra of SbI and AsI[1] and with the theoretical expectations.[2]

[1] M. Hults and S. Mrozowski, Phys. Rev. **86**, 587 (1952).
[2] Shortley, Aller, Baker and Menzel, Astrophys. J. **93**, 178 (1941).

R4. Forbidden Lines in the Spectrum of Bi II. C. D. COLE AND S. MROZOWSKI, *University of Buffalo.*—The spectrum of bismuth was excited by high-frequency oscillations under well controlled conditions (temperature and pressure), the apparatus being an improved version of the one used in the study of the Bi I spectrum.[1] Several forbidden lines corresponding to transitions between levels all belonging to the configuration $(6p)^2$ in Bi II were identified and found to be the strongest at vapor pressures of bismuth somewhat lower than those for which the forbidden lines of Bi I appear with greatest intensity. The lines found are: λ3241 ($^1S_0 \rightarrow {}^3P_1$) a pure magnetic dipole line similar to the well-known line λ4618 of PbI, λ4850 ($^1D_2 \rightarrow {}^3P_1$) and λ5914 ($^1D_2 \rightarrow {}^3P_2$) both mixed character (electric quadrupole and magnetic dipole), and finally a line λ7504 ($^3P_1 \rightarrow {}^3P_0$) of a pure magnetic dipole type for the first time observed as a nonintercombination transition. A line is observed at λ3683, the expected position for the pure electric quadrupole transition $^1S_0 \rightarrow {}^3P_2$, but its excitation conditions and too high intensity make it certain that it is not the forbidden line sought. A study of the hyperfine structure of the lines found is in progress.

[1] S. Mrozowski, Phys. Rev. **69**, 169 (1946).

R5. Raman and Infrared Spectra of $C^{13}H_3I$. FORREST F. CLEVELAND, RICHARD B. BERNSTEIN, AND FRED L. VOELZ, *Illinois Institute of Technology.*—Raman (liquid) and infrared (liquid and gas, with KBr and NaCl prisms) spectra have been obtained for two mixtures of $C^{13}H_3I$ (9.3 and 61 atom percent) and $C^{12}H_3I$, and from these the vibrational spectrum of $C^{13}H_3I$ has been deduced. In the Raman spectrum, only $\nu_2(a_1)$—the C−I stretching frequency—could be resolved from the $C^{12}H_3I$ lines; the isotopic shift was 17.7±0.5 K (K = kaysers = cm^{-1}). In the infrared spectrum (gas), five isotopic shifts were obtained; they were: $\nu_1(a_1)$10±3, $\nu_2(a_1)$5.5 ±1.0, $\nu_3(a_1)$16.1±1.0, $\nu_5(e)$4.6±0.6, and $\nu_6(e)$3.7±0.3 K. For the remaining fundamental, $\nu_4(e)$, the shift was obtained by use of the Redlich-Teller product rule; the value was 9.4±2.3 K. Analysis of the perpendicular bands yielded, with the aid of microwave data, values of the rotational constants, Coriolis interaction constants, and band origins for the $\nu_6(e)$, $\nu_5(e)$, and $\nu_4(e)$ bands of $C^{12}H_3I$ and $C^{13}H_3I$, though the values for the $\nu_4(e)$ band of $C^{13}H_3I$ are only estimated values since the sub-bands were not resolved in this case.

R6. Raman and Infrared Spectra of Dimethyltriacetylene. ALFONS WEBER, FORREST F. CLEVELAND, AND SALVADOR M. FERIGLE, *Illinois Institute of Technology.*—The infrared spectrum of $H_3C-C\equiv C-C\equiv C-C\equiv C-CH_3$ (2,4,6-octatriyne) has been obtained in the region 400–4000 K, for both CCl_4 and CS_2 solutions, with a Perkin-Elmer double beam spectrometer with NaCl optics and a Beckman IR-2 spectrometer with KBr optics. The agreement with results privately communicated by E. R. H. Jones is good. Except for the $-C\equiv C-$ stretching frequency in the series of molecules $H_3C-(C\equiv C)_n$

$-CH_3$ ($n=2$ to 6),[1] no infrared spectral data could be found in the literature. The Raman spectrum has been obtained with a Hilger E-612 spectrograph with exchangeable cameras, utilizing previously described methods.[2] The Raman shifts obtained in CCl_4 solution are: 337, 342, 483, 1074, 1129, 1377, 1522, 2148, 2179, 2227, 2775, and 2917 K.[3] Work on the Raman spectrum in CS_2 solution and the determination of reliable depolarization factors is in progress.

[1] Cook, Jones, and Whiting, J. Chem. Soc. **1952**, 2883.
[2] F. F. Cleveland, J. Chem. Phys. **11**, 1, 227 (1943); **13**, 101 (1945).
[3] K = kaysers = cm^{-1} [see J. Opt. Soc. Am. **43**, 410 (1953)].

R7. Rotational Excitation of Momonuclear Molecules.* S. STEIN, E. GERJUOY, AND T. HOLSTEIN, *University of Pittsburgh and Westinghouse Research Laboratories.*—Cross sections are calculated for excitation of rotation of diatomic homonuclear molecules by very slow electrons (energy ~ 0.1 ev) with neglect of exchange. It is assumed that the excitation results from interaction of the electron with the quadrupole field of the molecule; for this type of potential, use of the Born approximation is defensible at these low energies. For kinetic energies large compared to the separation of rotational levels, the cross section approaches a constant value $\sim 10^{-17}$ cm^2, using measured quadrupole moments.[1] The average fractional energy losses per collision in N_2 and H_2 are evaluated and are in moderately good agreement with recent measurements.[2]

* This research was supported in part by the U. S. Air Force.
[1] W. V. Smith and R. Howard, Phys. Rev. **79**, 132 (1950).
[2] R. W. Crompton and D. J. Sutton, Proc. Roy. Soc. (London) **A215**, 467 (1952).

R8. Threshold Field *vs* Temperature Slope for Paraelectric-Ferroelectric Change in $BaTiO_3$. A. DEBRETTEVILLE, JR., AND E. D. HARRIS, *Signal Corps Engineering Laboratories.*—Recent work of Merz[1] and others has shown that the paraelectric-ferroelectric phase change in $BaTiO_3$ is a first-order transition. A relation[2] developed by one of us for the slope of the threshold field E_t *vs* the temperature for the antiferroelectric to ferroelectric phase transition in lead zirconate can be applied to calculate the paraelectric-ferroelectric phase transition in $BaTiO_3$. The equation of the initial slope is $(\partial E_t/\partial T)_{E=0} = \Delta H/T_c N v \Delta P$, where ΔH is the heat of transition, T_c the Curie temperature, Nv the atomic volume, and ΔP the jump in spontaneous polarization. Using our single crystal oscilloscope data for $\Delta H/T_c$ obtained from the slope of the free energy *vs* temperature, we obtain 1.06 kv/cm°C compared to an observed 1.26 kv/cm°C. Calculation of the slope from the above formula using the data of Merz' crystal[1] and taking 46.6 cal/mole for ΔH gives 0.74 kv/cm°C compared to his experimental value of 0.70 kv/cm°C, while the Devonshire theory, using Merz' data[1] gives 0.53 kv/cm°C.

[1] W. J. Merz, Phys. Rev. 513–517 **91**, (1953).
[2] A. deBretteville, Jr., Phys. Rev. 213(A) **91**, (1953).

R9. Dielectric Absorption of Liquid Crystalline Biaxial Molecules. C. KIKUCHI, *Electricity Division, Naval Research Laboratory.*—To account for the anisotropic absorption of liquid crystals in a steady magnetic field,[1] Debye's theory of dielectric absorption was generalized.[2] The molecules of liquid crystals that have been investigated are characterized by two axes, the electric and the magnetic. Consequently the steady magnetic field tends to freeze the motion of the magnetic axis, whereas the electric axis will attempt to follow the electric field. In addition, the molecular axes will undergo rotational Brownian motion. The diffusion equation, to which the above processes lead, is similar to the one given by Gans and Perrin.[3] The solution of the equation for various cases will be discussed.

[1] E. F. Carr and R. D. Spence, Phys. Rev. **90**, 339 (1953).
[2] P. Debye, *Polar Molecules*, p. 77.
[3] R. Gans, Ann. Physik **86**, 628 (1928); F. Perrin, J. phys. **5**, 497 (1934).

R10. A New Method of Calculation of Effective Ionic Radii of Lanthanides. N. EFREMOV, *1061 Intervale Avenue, New York, N. Y.*—The effective ionic radii of lanthanides may be obtained from the ionic radius of lanthanum. According to our method of calculation of effective ionic radii[1] the radius of lanthanum may be determined by means of the general formula: $R(\mathrm{La}) = (n \times K)P$, where n is the principal quantum number, K is the matrix number corresponding to the given ions, and P (portion) is a constant ($P = 0.01462369$A) which can be derived from the Rydberg constant. Thus $R(\mathrm{La}) = (6 \times 14)P = 84P$; $R(\mathrm{La}) = 1.22$A. The formula for calculation of the ionic radii of lanthanides[2] is the following: $R = 84P - (Z - 57)P$, where Z is the atomic number of any lanthanide and 57 is the atomic number of lanthanum, e.g., $R(\mathrm{Gd}) = 84P - (64 - 57)P = 77P = 1.11AE$. The number of portions directly decreases by one with the direct increase of the atomic number of the rare earth element by one. Values calculated by means of this formula are in substantial agreement with the values determined by V. M. Goldschmidt (who found $R(\mathrm{La}) = 1.22$A, $R(\mathrm{Gd}) = 1.11$A) and by K. Stockar.

[1] Paper given at the September 1953 meeting of the American Physical Society in Albuquerque, New Mexico.
[2] For the crystalline lattices of the NaCl type.

SATURDAY AFTERNOON AT 1:30

Oriental Institute

(E. M. LONG presiding)

Cryogenics; Theoretical Physics

T1. Hall Effect in Bismuth at Low Temperatures.* LAIRD C. BRODIE, *Northwestern University.*—The Hall effect and magnetoresistance of bismuth monocrystals have been measured at 14°K as a function of magnetic field strength to 18 kilogauss. The trigonal axis was parallel to the specimen axis, and the magnetic field was perpendicular to a binary axis. Using residual resistance and magnetoresistance as a criterion of perfection and purity, the best crystals proved superior to those of Gerritsen and de Hass,[1] and compared favorably with those grown by Schubnikow and de Haas, and Alers and Webber. For the orientation measured, the Hall coefficient is negative and increases in magnitude monotonically to 6500 emu at 18 kilogauss. The slope of the curve is less between 10 and 12 kilogauss, and also between 16 and 18 kilogauss, corresponding to the anomalies at these same field strengths in the magnetoresistance curve at 14°K. These results indicate that, while there is a parallelism between the field dependence of the Hall coefficient and the de Haas-van Alphen effect, this parallelism is of the same character as that between magnetoresistance and de Haas-van Alphen effect, rather than that found by Gerritsen and de Haas.[1]

* Supported by the National Science Foundation.
[1] Gerritsen and de Haas, Physica **7**, 802 (1940).

T2. A Strong-Field Induced Paramagnetic Anomaly in $NiSiF_6 \cdot 6H_2O$. WARREN E. HENRY, *Naval Research Laboratory.*—The Brillouin mathematical simplification of the space quantized dipole model has been previously tested up to practical (99.5 percent) saturation[1] for substances chosen so as to minimize interionic interaction. It was pointed out that this Brillouin dependence requires linearity of the pertinent energy levels with field. There has been considerable speculation on the causes and consequences of nonlinear field dependence of these energy levels.[2] We have chosen a case (nickel fluosilicate) in which the higher power terms may be significant at attainable high fields. The magnetization of nickel fluosilicate has been carried out in the liquid helium range (1.3–4.2°K) and in magnetic fields up to 60 000 gauss. For H/T about 5000 gauss/deg, the magnetic isotherms practically superimpose to within about 1 percent. However, for high values of H/T, this apparent superposition is lost and for a given value of H/T, the lower the temperature, the lower the moment. The total moment separation is greater than 6 percent for 14 000 gauss/deg. The introduction of a suitable quadratic dependence of the energy levels gives qualitatively the moment branching which is observed experimentally.

[1] W. E. Henry, Phys. Rev. **88**, 559 (1952).
[2] J. H. Van Vleck (private communication); E. F. Carr and C. Kikuchi, Phys. Rev. **80**, 1107 (1950); O. M. Jordahl, Phys. Rev. **45**, 87 (1934).

T3. Some Thermodynamic Properties of $Mn(ND_4)_2(SO_4)_2 \cdot 6D_2O$ Below 1°K. J. W. T. DABBS AND L. D. ROBERTS, *Oak Ridge National Laboratory.*—In connection with the Mn^{55} nuclear polarization experiments using $Mn(ND_4)_2(SO_4)_2 \cdot 6D_2O$, reported elsewhere at this meeting, we have made measurements of the magnetic moment and absolute temperature of this salt as a function of final field in adiabatic demagnetizations from fields of 10–17 kilogauss and temperatures of ~1.2°K. These measurements have been carried out over a final field range $0 < H_f \leq 4560$ gauss, and a temperature range 0.119°K–0.35°K. γ-ray heating was used to establish one point at 0.201°K of the $T-H$ relation with M as the "thermometric parameter," and the region was covered using the equation

$$T_1 - T_2 = \int_{H_1}^{H_2} (\partial M/\partial S)_H dH.$$

Calibration of the γ-ray heat input was obtained by direct comparison with a measured electrical heat input in the region 0.4–0.5°K. This approach has several advantages. A curve of measured specific heat *versus* magnetic temperature in the region 0.3–0.8°K is presented.

T4. The Interaction between Two Nucleons at Low Energies.* DAVID FELDMAN, *The University of Rochester.*—We have investigated the problem of the derivation of a two-nucleon Schrödinger equation from quantum field theory, taking into account only those mesons which are exchanged between the nucleons. One expects that the two-particle Schrödinger picture will be useful if the energy (less rest energy) is small ($\sim\mu^2/M$), and if the important matrix elements are those which couple states of small momenta ($\sim\mu$). Our procedure has been to go over to Fock space in the manner of Tamm and Dancoff, and then to decouple the two-particle T.D. amplitude from all the others by a series of canonical transformations (the over-all coupling is assumed weak). Unlike the methods developed by Lévy-Klein and Bethe-Salpeter, the characteristic difficulties such as energy-dependent and non-Hermitian potentials are avoided. We have thus far used the formalism to analyze the second- and fourth-order adiabatic nuclear forces for the neutral scalar and charge-symmetric *ps-ps* theories. In this approximation, there is agreement with the results of Lévy-Klein, as is expected. It should be emphasized that the "non-adiabatic velocity-dependent" corrections of Lévy-Klein appear explicity, in our treatment, as the adiabatic higher-order ladder corrections to the second-order potential, and cannot be dropped, as has been suggested.

* This research was supported by the U. S. Atomic Energy Commission.

T5. Positon Theory without "Holes." F. J. BELINFANTE, *Purdue University.*—By modification of Fock's formalism of second quantization one can formulate positon theory avoiding Dirac's "hole" concept altogether, and one can ascribe wave functions in configuration space to states with finite numbers of positons and negatons. The wave functions are no arbitrary functions, but are superpositions of positive free-electron energy states only. Explicit formulas can be given for the superposition of many-free-electron states describing the "bound" electron vacuum or the bound electron of a hydrogen ion or atom, and for the operation of the quantized ψ-function on many-electron wave functions. Operators for observables are defined by the Furry-Oppenheimer prescription. If one wants to treat the bound vacuum as a no-electron state and use the total electron energy for judging energy signs, then the Dirac-Heisenberg-Kramers definition of operators for observables must be used, and a trivial infinity thus introduced for certain observables must be subtracted. Problems of vacuum polarization etc. can be treated by this formalism, which differs from the conventional hole theory not by its essential contents but by its less controversial formulation allowing an easier interpretation in a language similar to that used in Schrödinger's wave mechanics.

T6. A New Modification of Classical Electromagnetic Theory. A. SCHILD, *Carnegie Institute of Technology.*—Modifications of classical electrodynamics have been suggested by Bopp,[1] Peierls and McManus,[2] Feynman,[3] and others.[4] A new modification has been studied in which the rest mass of a charged particle is treated as a variable of the motion. A new action principle for classical electrodynamics been obtained which is simpler than the usual one. In this new action principle, the rest mass of a particle is varied as well as its coordinates. The constancy of the rest mass then follows as a consequence of the equations of motion. Modifications of the old action principle can yield finite electromagnetic rest masses which are, however, determined uniquely by the particular "structure function" used in the modification; thus, for example, this unique rest mass can be fitted to that of electrons or of protons, but not to both. Similar modifications of the new action principle give purely electromagnetic rest masses to all charged fundamental particles. In this new modification of electrodynamics, particles interacting at small distances no longer have constant rest masses.

[1] F. Bopp, Ann. phys. **42**, 573 (1943).
[2] R. E. Peierls and H. McManus, Proc. Roy. Soc. (London) **A195**, 323 (1948).
[3] R. P. Feynman, Phys. Rev. **74**, 939 (1948).
[4] See review article by H. Hönl, Erge. exakt. Naturw. **26**, 291 (1952).

T7. On a Class of Solutions of Maxwell's Equations.* G. E. HUDSON, *New York University,* AND D. H. POTTS, *Navy Electronics Laboratory.*—The usual plane wave solutions of Maxwell's electromagnetic equations in a homogeneous isotropic medium are exceedingly special in that the phases of the electric and magnetic vectors differ by a constant and their amplitudes are in a constant ratio. This suggests that one should investigate plane wave solutions in which this specialization is not made at the outset. Maxwell's equations then furnish the necessary condition that the phases of the two vectors are not only functionally related but their phase difference satisfies a certain nonlinear ordinary differential equation of second order. Since the usual plane wave solutions correspond to singular solutions of this equation, the question of the stability of the usual solutions in an important one and will be discussed. The amplitude ratio, too, is seen to depend on this phase difference, indicating that the concept of a characteristic impedance of the medium would need to be generalized for use with such waves. If, in addition, one considers certain generalized solutions of this kind which do not necessarily represent plane waves, a further consequence is that the spatial part φ of the phase function of the waves exactly satisfies an eikonal equation, and the electric and magnetic vectors are orthogonal to each other and to the direction of propagation of the wave.

* Work performed while Professor Hudson was in residence at the Navy Electronics Laboratory, summer of 1953.

T8. A Kinetic Approach to Collision Processes in Gases. I.* M. KROOK AND P. L. BHATNAGAR, *Harvard University,* AND E. P. GROSS, *M.I.T.*—A kinetic theory approach to collision processes in gases is presented. This approach is adequate for the unified treatment of many of the dynamic properties of gases over a continuous range of pressures from the Knudsen limit at low pressures to the high-pressure limit where the aerodynamic equations are valid. It is also possible to satisfy correct microscopic boundary conditions. The method consists in altering the collision terms in the Boltzmann equation so that a mathematically more tractable equation results. The modified collision terms are constructed so that each collision conserves particle number, momentum, and energy; other characteristics such as persistence of velocities and angular dependence may be included. An extreme case of the general model involves the establishment of equilibrium in a time equal to the mean time between collisions; another extreme case involves an infinite relaxation time.

* Sponsored by the U. S. Office of Naval Research, the U. S. Army Signal Corps, and the U. S. Air Force.

T9. A Kinetic Approach to Collision Processes in Gases. II.* E. P. GROSS, *M.I.T.,* AND M. KROOK, *Harvard University.*—The method described in the previous abstract is applied to the study of the small amplitude oscillations of one-component ionized and neutral gases. The initial-value problem in unbounded space is solved in detail for a simple collision model involving the assumption of a collision time independent of velocity. For uncharged gases, there results the corrected adiabatic limiting law for sound-wave propagation at high pressures. In addition, one obtains a theory of the absorption and dispersion of sound for arbitrary pressures. For ionized gases the difference in the nature of the organization in the low-pressure plasma oscillations and in high-pressure sound-type oscillations can be studied. At high pressures it is not permissible to treat an ionized gas as a one-component system; the electron ion coupling must be studied more carefully. The approach of the previous abstract is therefore generalized to treat many-component systems and is applied to the treatment of the oscillations of ionized gases and to the propagation of sound in mixtures of neutral gases.

* Sponsored by the U. S. Office of Naval Research, the U. S. Army Signal Corps, and the U. S. Air Force.

T10. On the Universal Fermi Interaction. E. J. KONOPINSKI, *Indiana University.* (30 min.)

SUPPLEMENTARY PROGRAMME

SP1. Interaction of μ^- Mesons with I^{127}. LESTER WINSBERG, *University of Chicago.**—One-kilogram samples of iodine were exposed to the negative muon beam from the Chicago synchrocyclotron.[1] Radiochemical purification revealed the presence of Te isotopes of mass 125 and 127 in relatively high yield, Sb isotopes of mass 122 and 124 in low yield, and the absence of isotopes of mass 117 and 118 and Sb isotopes of mass <121. The intensity of the muon beam was not large enough to permit the detection of any Sn isotopes. These results indicate that the average number of nucleons emitted per muon captured is much smaller than is the case for pion capture[2] and that the probability of charged particle emission is low in agreement with the counter studies of Conforto and Sard[3] and the photographic plate work of Fry.[4] Thus further proof is given for the weak nature of the interaction of negative muons with nuclear matter.

* To be given at the end of Session B if the Chairman rules that time permits.

[1] L. Winsberg, paper B8 in this *Bulletin*.
[2] L. Winsberg, Phys. Rev. **90**, 343(A) (1953).
[3] A. M. Conforto and R. D. Sard, Phys. Rev. **86**, 465 (1952).
[4] W. F. Fry, Phys. Rev. **85**, 676 (1952).

SP2. Observation of Diffusion Effects Occurring During the Artificial Aging of Dual Layer Bi-Metal Films.* RICHARD B. BELSER AND MARGARET C. CHESTER, *Georgia Institute of Technology.*†—During the artificial aging by heating of dual-layer metal films in the infrared vacuum oven films of the colored metals, copper and gold were observed to disappear at certain temperatures by intermingling with their partner films. Gold evaporated onto an indium film disappeared at the temperature of the substrate during the evaporation process. Paired with silver, the gold disappeared at 120°C and 175°C when it, respectively, overcoated and undercoated the silver. For gold and copper paired with aluminum, there was a distinct difference between the temperatures of disappearance according to whether they undercoated or overcoated the aluminum. In the undercoating position, these temperatures were 190°C and 260° for gold and copper, respectively, whereas in the overcoating position the temperatures of 480°C and 495°C, respectively, were recorded. The differences in temperatures of intermingling, in accordance with position in regard to the aluminum film, imply the presence of a barrier on the surface of the aluminum film. Resistance and x-ray data confirm its presence. The barrier remained effective up to temperatures of approximately 450°C and is believed to consist of aluminum oxide formed within the vacuum chamber, at pressures under 8×10^{-6} mm of mercury, during the short interval between successive film depositions.

* Supported in part by the U. S. Signal Corps.
† To be given at the end of Session N if the Chairman rules that time permits.

SP3. Effects of the Alloying Actions of Dual-Layer Bi-Metal Electrodes on the Frequencies of Piezoelectric Quartz Resonators.* RICHARD B. BELSER AND WALTER H. HICKLIN, *Georgia Institute of Technology.*†—Aluminum overcoated separately with silver and gold, and nickel undercoated separately with silver, gold, and copper, have been deposited as electrodes on 6-mc AT-cut quartz resonator blanks. The crystal blanks, after plating by evaporation, sputtering, or electroplating, were mounted and oscillated continuously in Pierce-type oscillators at a constant temperature (48°C). Daily frequency measurements were made. Of the metal pairs examined, only silver plus nickel gave resonators of exceptional stability. These changed only 30 cycles in 180 days. Sputtered gold plus electroplated nickel, on limited tests, showed good stability. The crystals coated with other metal pairs changed hundreds of cycles within 30 days. The behavior of these metal pairs as electrodes, from the standpoint of stable frequency performance of the coated resonators, appeared to correlate with the alloying properties of the metals employed as defined by the known binary alloy phase diagrams. The techniques employed, in conjunction with the studies performed concurrently by resistance and x-ray diffraction measurements, appear to provide an additional means of measuring alloying rates and affinities of suitable metal pairs.

* Supported by the U. S. Army Signal Corps.
† To be given at the end of Session N if the Chairman rules that time permits.

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